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Gypsum in Northern Ontario:

Resources and Market Potential

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Survey

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Photo cover inset: Moulded ornamental rosette made from calcined gypsum plaster. Photo courtesy of Ontario Ministry of Northern Development and Mines.

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Executive Summary

THE NORTH AMERICAN MARKET FOR "SPECIALTY" OR HIGH purity gypsum/calced gypsum products amounted to approximately one million tons in 1987. Of this total, building plasters accounted for 25%, industrial plasters 50% and the balance was consumed in various filler and extender applications. Demand for building plasters is expected to remain stable with growth in demand of products for other uses estimated to be in the order of 2% to 3.5% annually. This high purity market, highly fragmented in terms of end use, is closely controlled by two U.S.-based producers: USG Corporation and Georgia Pacific Corporation. This market can be very profitable, with gross margins in the range of 50% to 100% for various products not unusual. Prices for these products ranged from approximately U.S. \$35 to over U.S. \$400 per ton in 1987.

High purity gypsum nominally refers to gypsum of at least 90% purity and generally above 97% purity. In the Moose River Basin in Northern Ontario, beds of massive to banded gypsum, averaging >96% gypsum, outcrop over an area roughly 17 km wide by 70 km long. Limited diamond drilling has intersected up to 33 m of massive, white gypsum to a depth of 40 m. The chemical and mineralogical compositions of these beds suggest that this gypsum may be able to meet industry specifications for the production of building and industrial plasters and certain filler grades.

Successful development of these deposits will be dependent upon several factors, the chief ones being:

- more detailed knowledge of the geology and quality of the deposits
- development of innovative transportation programs to overcome the cost penalties associated with development of remote mineral deposits
- overcoming deficiencies in the infrastructure currently in place
- detailed knowledge of end use process requirements, excellent marketing and distribution skills and excellent product development skills.

mation on these operations. Essentially all the gypsum mined in Ontario is used in wallboard manufacture.

Gypsum is generally considered to be a low value commodity material. The principal end-use of the material is in the manufacture of wallboard. Wallboard production accounts for over 70% of total gypsum demand in the United States and even more in Canada. Other major uses of gypsum are as a set controlling agent in portland cement and as a fertilizer and soil conditioner in agriculture. In these uses gypsum had a value in 1988 ranging from \$6.00 to approximately \$20.00 per ton, FOB mine site* in North America. Higher value uses for gypsum include building and industrial plasters; fillers in food, pharmaceutical, plastic and paper products; set control agents for oil well cements; dental plasters; and a host of specialist applications in industrial processes. These high value applications can fetch prices of over \$200 per ton FOB mine site, and were the principal subjects of the market study by Hains Technology Associates.

*Unless otherwise stated, all values are in U.S. dollars and short tons (2000 pounds).

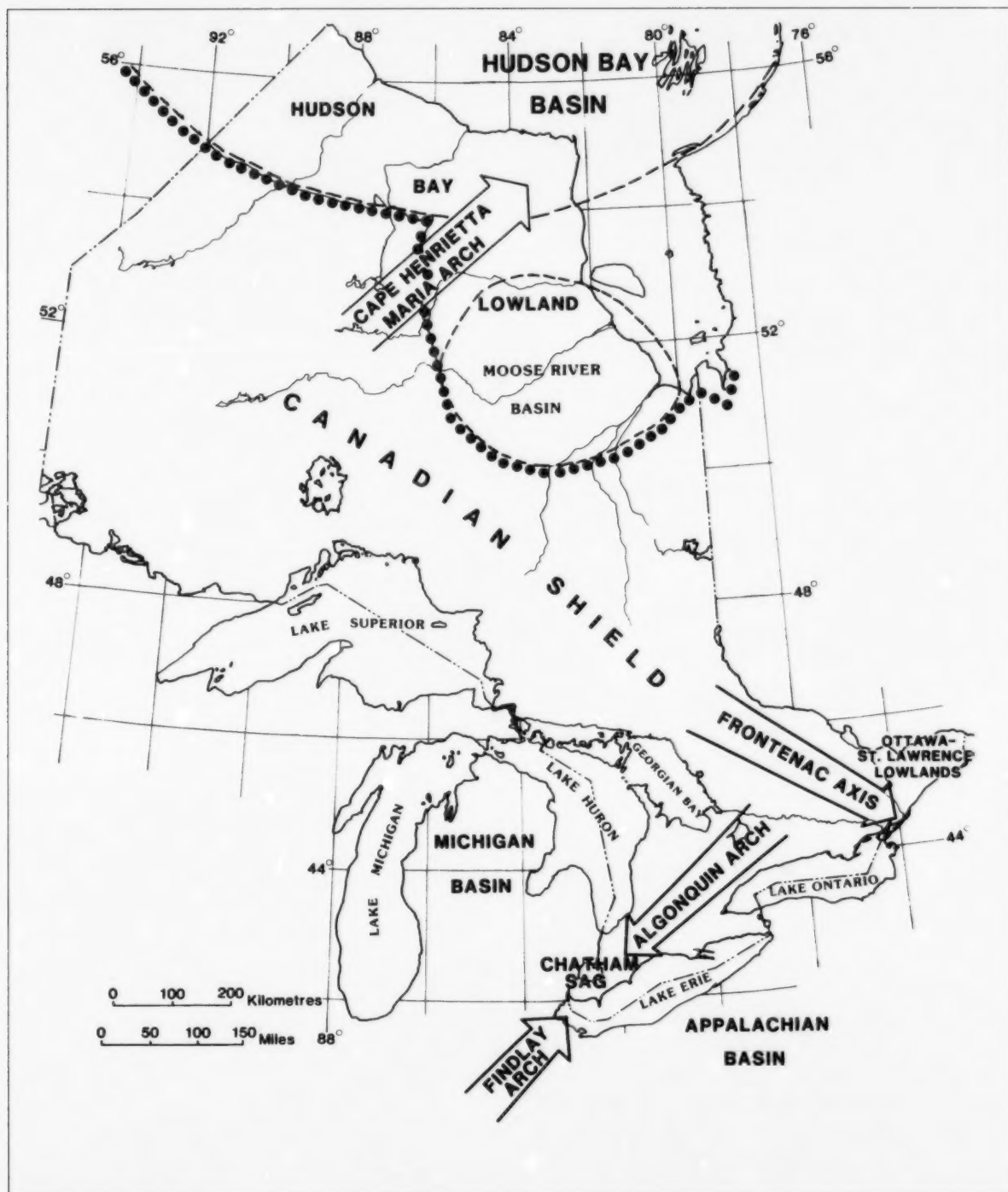


Figure 1:
Sedimentary Basins, Physiographic Elements, and Structural Features in Ontario. Basins are outlined with dashes and the lowlands are outlined with dots.

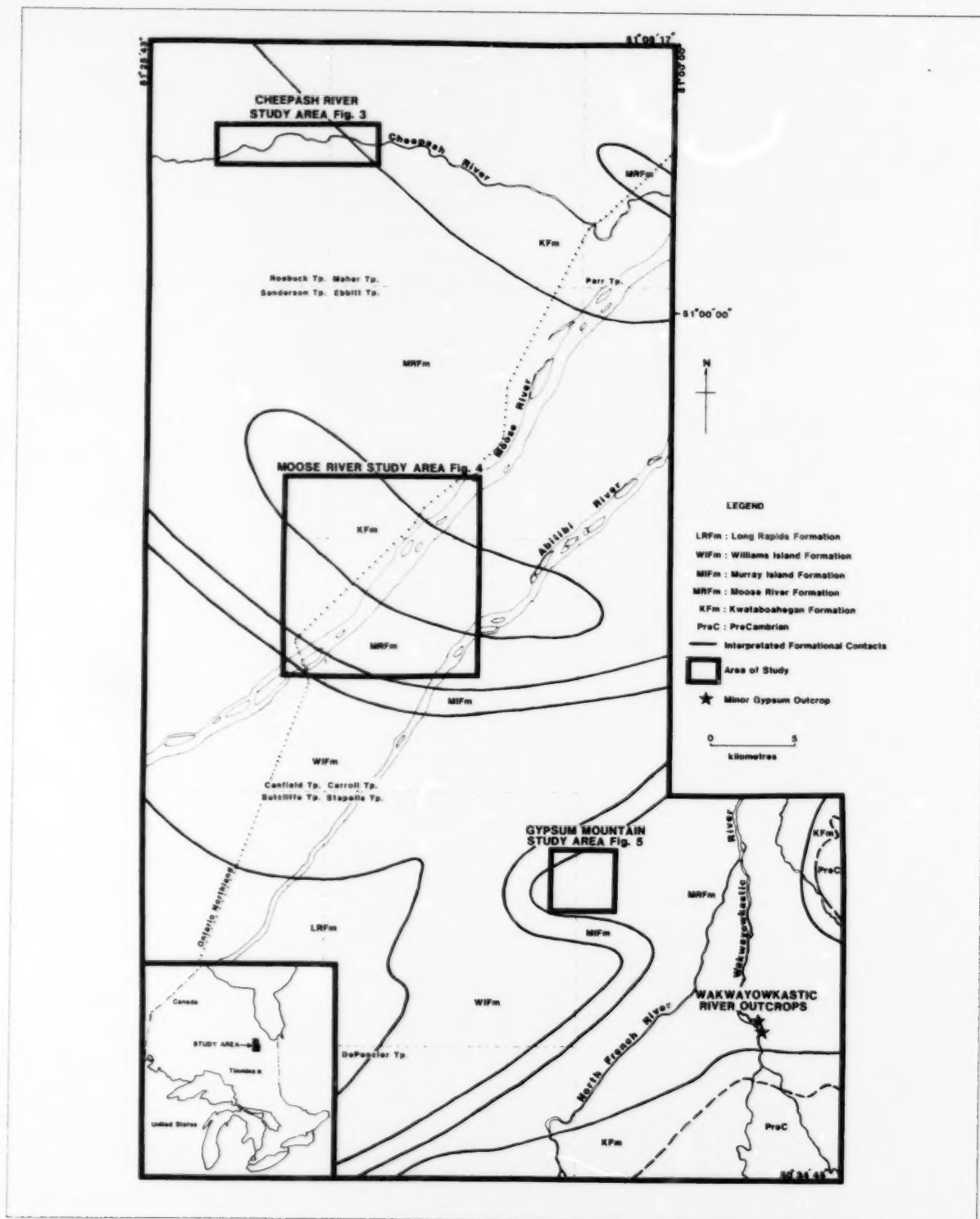


Figure 2:
Gypsum in the Moose River Basin

2. Gypsum Resources of Northern Ontario

2.1 General Geology

A total thickness of Paleozoic/Mesozoic strata of less than 1000 metres overlies Precambrian basement rocks in the Moose River Basin. Paleozoic rocks in the Moose River Basin range in age from Upper Ordovician to Upper Devonian (Telford, 1989), and are succeeded by Mesozoic rocks in the southern portion of the basin (Telford and Long, 1986). Devonian age rocks constitute most of the Paleozoic stratigraphic sequence (approximately 400 metres) in the basin and are represented by the following units (in ascending stratigraphic order) (Figure 3): the upper member of the Kenogami River Formation and the Sextant, Stopping River, Kwataboahagan, Moose River, Murray Island, Williams Island, and the Long Rapids Formations. All but the Sextant and Long Rapids Formations are marine carbonate units with significant evaporites occurring in the Moose River Formation and shales in the Williams Island Formation. Quaternary and Recent deposits blanket the entire area.

The Middle Devonian Moose River Formation consists of a unfossiliferous sequence of limestone, dolomitic limestone, dolostone, brecciated carbonates, gypsum, minor amounts of anhydrite, some shale, and secondary selenite. It conformably overlies the Kwataboahagan Formation, which consists of massive to thick bedded, fossiliferous, limestones. The Moose River Formation is disconformably overlain by the Murray Island Formation, a banded sequence of calcareous dolostone, limestone, and argillaceous limestone (containing clay minerals). A diagnostic tool to distinguish the Moose River Formation carbonates from either the Kwataboahagan or Murray Island Formations (in drill core or outcrops) is its scarcity of fossils.

2.2 Gypsum in the Moose River Basin

Introduction

The maximum development of Moose River Formation gypsum occurs along the Moose River Arch, a broad anticlinal northwest-trending basement high (Figure 4). This area of gypsum outcropping is approximately 70 km long and about 17 km wide when an ellipse is drawn from the Wakwayowkastic River in the southeast to the Cheepash River in the northwest. In drill holes to the southwest and northeast of this outcrop belt, only minor amounts of gypsum were intersected.

An interval of 80.2 m of the Moose River Formation is encountered in drillhole #67 (The James Bay Basin Oil Company Limited, Well No.1; Satterly 1953) on Mike Island (See Figure 5), with 53.7 m of the interval consisting of interbedded gypsum, shale and limestone. Drillhole #68 (The James Bay Basin Oil Company Limited, Well No.2; Satterly 1953), adjacent to hole #67 on nearby Murray Island, encoun-

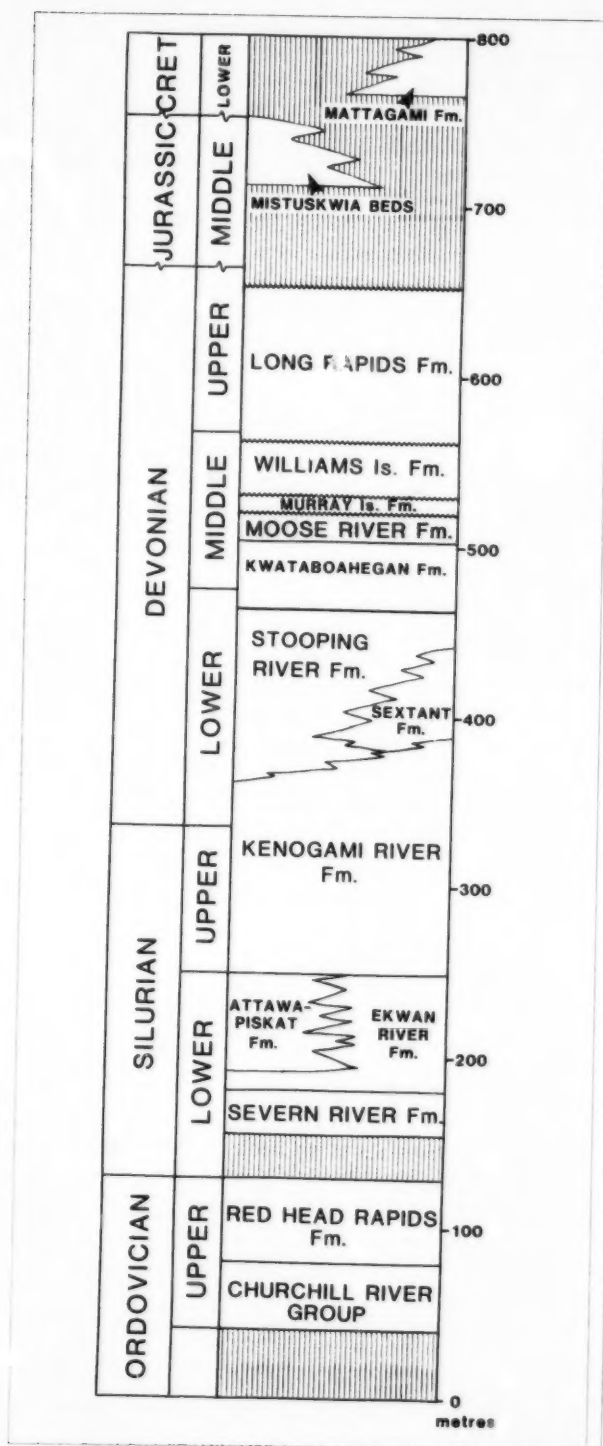


Figure 3:
Stratigraphy of the Paleozoic and Mesozoic units
in the Moose River Basin. The Moose River
Formation is highlighted.

tered 48.5 m of the Formation, with 19.6 m consisting of massive gypsum. Both of these drillholes are located a few kilometres southwest of the main gypsum outcrop belt.

An interval of approximately 5 m of gypsum occurs in the Ontario Department of Mines (ODM) Campbell Lake drillhole (#39) (Hogg et al. 1953; Sanford and Norris 1975), which is located near the southern margin of the Moose River Basin, and where part of the formation has been removed by erosion. A total of 29.2 m of the Moose River Formation is present in this hole. In the OGS Onakawana B drillhole (#77), only 0.45 m of massive gypsum was encountered in the Moose River Formation interval, compared to 17.8 m of gypsum breccia intersected (Bezys 1989).

Drillholes containing no massive gypsum, but some gypsum breccia, include the OGS Schlievert Lake hole (#74) and Dewson Mines 1A (#64.1). The remaining two holes, ODM Jaab Lake (#38) and Hydro-Electric Power Commission of Ontario Drillhole R-1 (#42) (Sanford and Norris 1975), are devoid of either massive gypsum or gypsum breccia.

Drilling on the Cheepash River (Figure 6) demonstrated the continuation of gypsum to a depth of 40 m. It also demonstrated a very irregular bedrock surface caused presumably by sinkhole development and deep glacial scouring. The best and most continuous intersections of gypsum were made near the middle of the Cheepash outcrop area (Figure 7), where 22 to 33 m of apparently very pure gypsum was encountered in several adjacent holes.

Core from drillholes #38, #39, and #42 is available at the Geological Survey of Canada core repository in Ottawa, Ontario. Drillhole core from #74 and #77 is stored at the Ministry of Northern Development and Mines Core Library in Timmins, Ontario. The locations of drill core from holes #64.1, #67, #68, and the Moosonee Gypsum and Exploration Company's Cheepash River drilling program are unknown.

Typically, gypsum outcropping along the Moose and Cheepash Rivers and at Gypsum Mountain is of a massive to banded, white variety (Plate 1). Other lithologies, including gypsum breccia, banded/impure gypsum and limestone are also present in outcrop. The following is a list of the lithologic facies (classifications) present in the three main study sites: (see also Figure 2)

- 1a: massive gypsum
- 1b: banded/impure gypsum
- 2: gypsum breccia
- 3a: interbedded limestone with gypsum
- 3b: interbedded gypsum with limestone
- 4a: limestone
- 4b: limestone breccia

The three most common facies are: massive gypsum (1a); banded/impure gypsum (1b); and gypsum breccia (2). The limestone and interbedded units are usually minor occurrences.

The banding present in the gypsum facies is usually caused by limy zones or coarsely crystalline selenite (Plates 2 and 3).

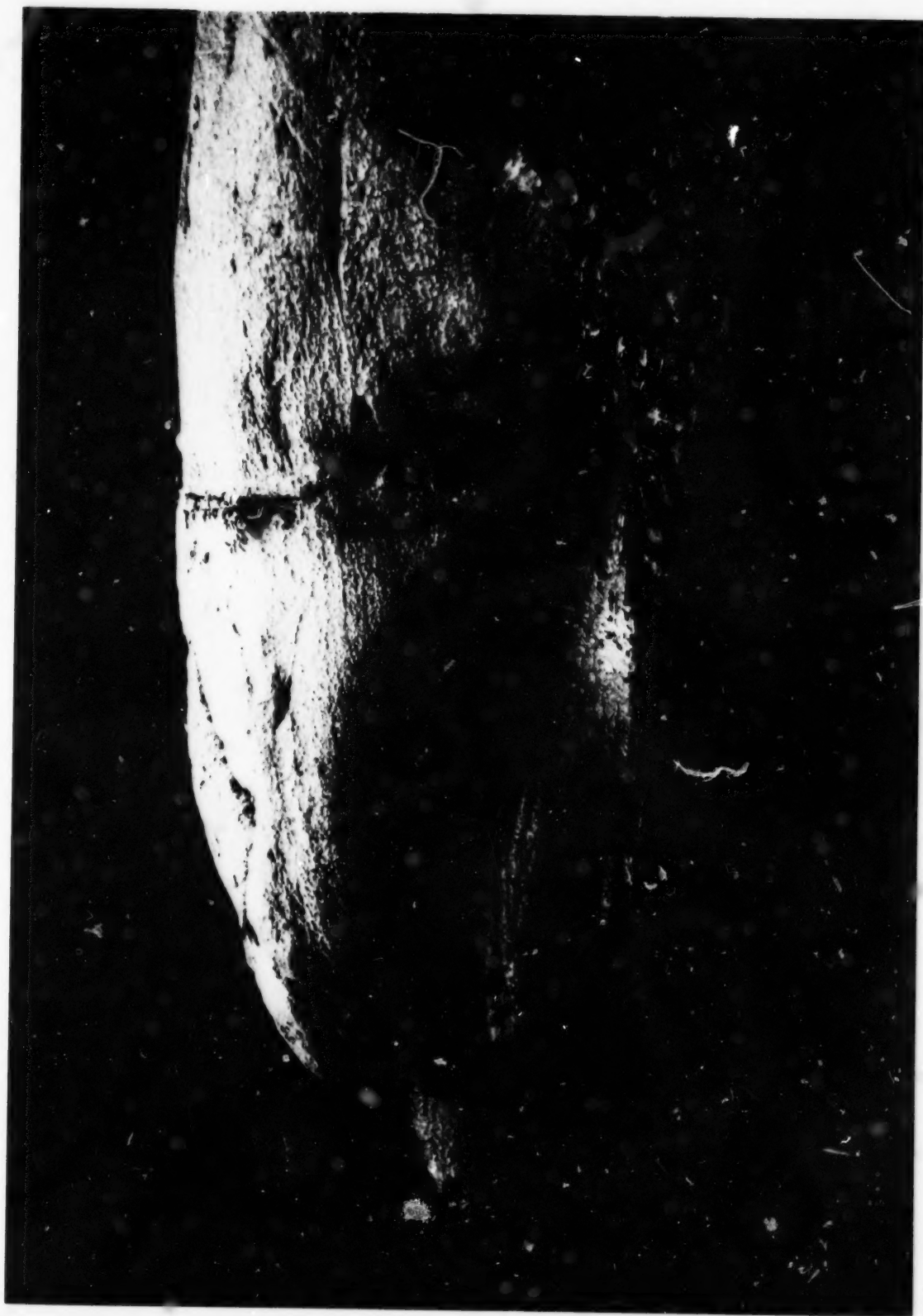


Plate 1:
Massive to banded white gypsum (facies 1a and 1b) in outcrop. Cheepash River.

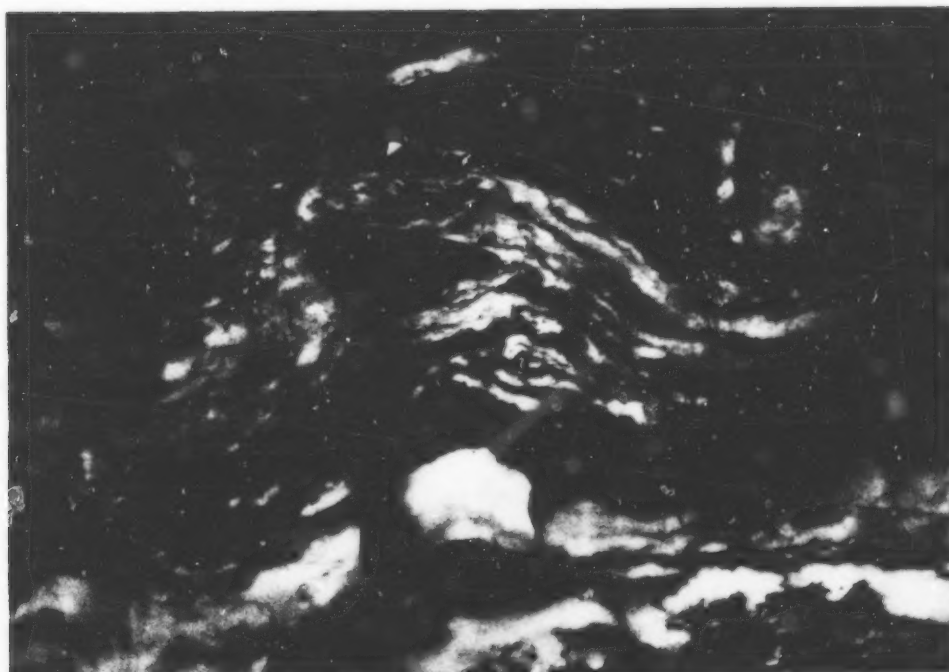


Plate 2:
Alternating bands of argillaceous limestone and white gypsum (facies 1b).
Cheepash River.



Plate 3:
Banded white gypsum and fine crystalline limestone (facies 1b). Cheepash River.

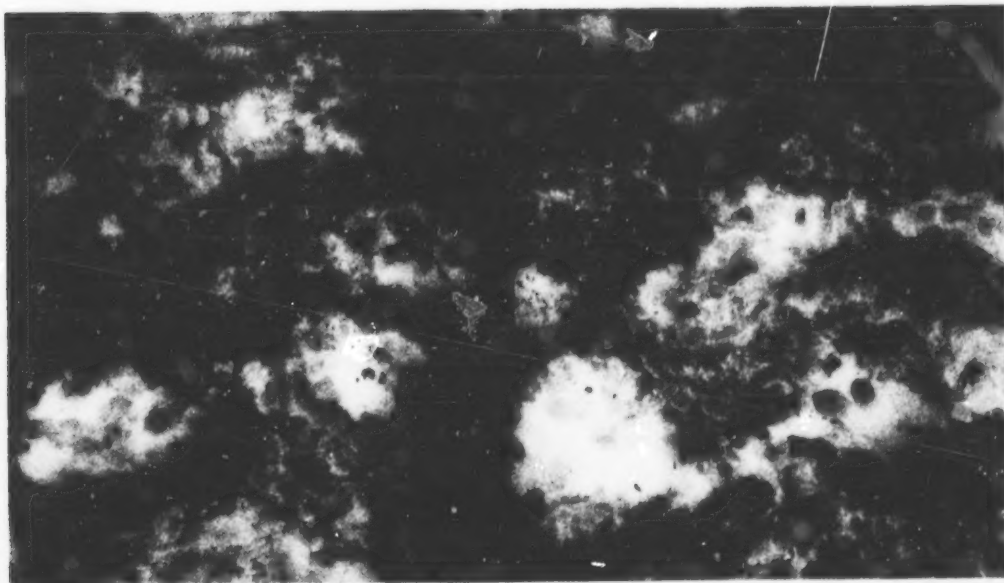


Plate 4:
Massive, impure gypsum with a chickenwire mosaic texture (facies 1b).
Note the very coarse crystalline "eye" of clear selenite. Cheepash River.



Plate 5:
Contact between the massive gypsum facies (1a) and the gypsum breccia facies (2).
The gypsum facies is mottled at the contact with brown to salmon-pink selenite. Note
the very argillaceous character of the breccia matrix and increase in clast size
upward. Moose River.

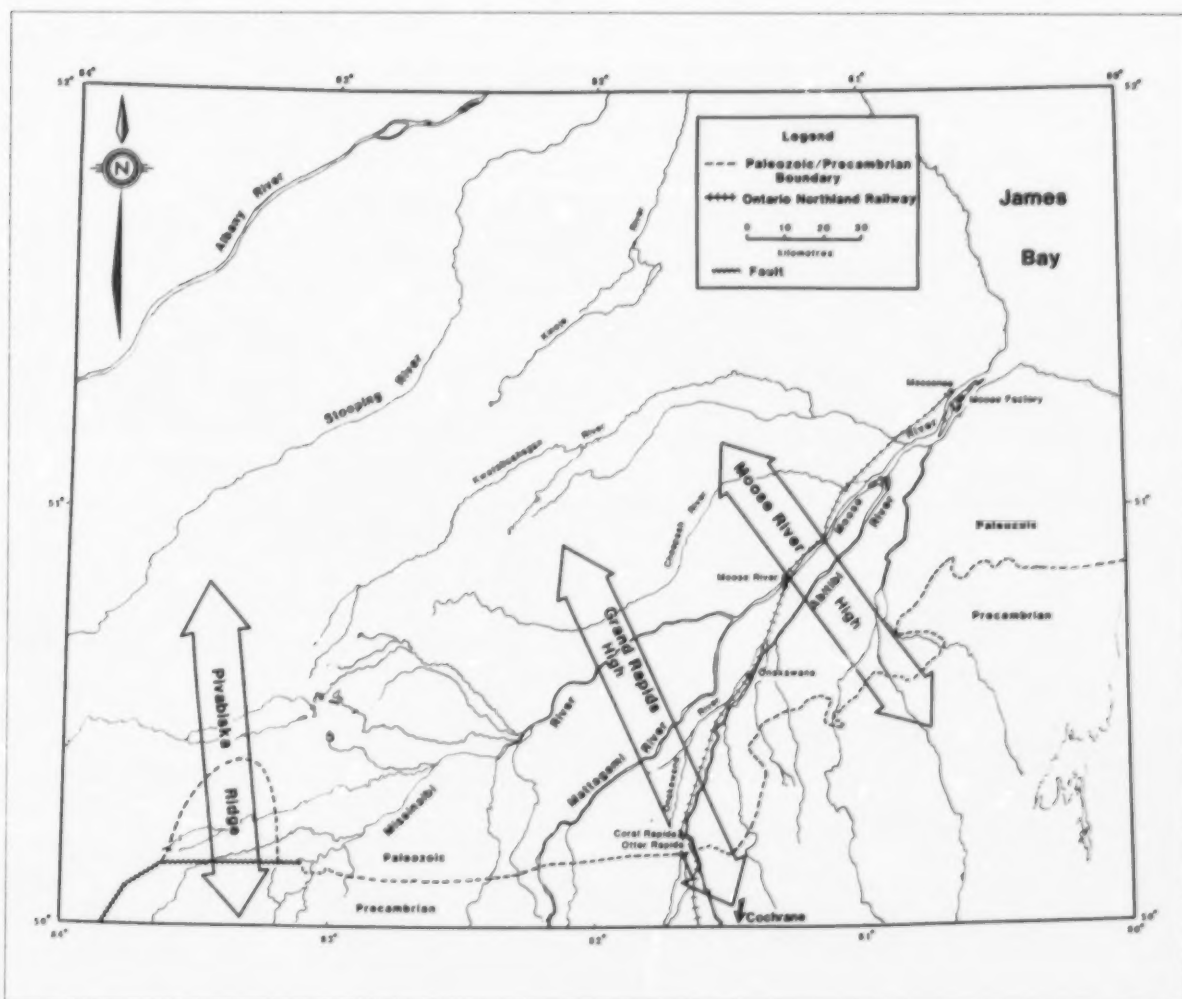


Figure 4:
Structural Map of the Southern Portion of the Moose River Basin, indicating the Moose River and Grand Rapids Arches and the Pivabiska Ridge.

Limestone beds, where present, consist of dark brown to tan, very fine to fine crystalline, laminated to massive limestone.

Outcrop exposures range in thickness from less than 0.5 m to about 12 m, with an average thickness of approximately 2.5-3.0 m.

The gypsum facies, in its finest form, is a pure white, finely crystalline, alabaster-like gypsum. When impurities are present, they occur either as laminations (as in Plate 1) or as mottles which are referred to as chickenwire mosaic texture (Plate 4). Impurities can consist of dark-coloured, coarsely crystalline selenite, limestone or organics such as bitumen.

Gypsum outcrops in the Moose River Basin are usually white in colour, but can also be light grey, amber, salmon-pink, and orange. In the massive gypsum unit (1a), these colour

variations become more common towards the top of the unit, at the contact with the breccia unit. Grain size and banding abundance also increase towards the top of the gypsum unit. It appears that where colour variations occur within an otherwise white gypsum, grain size will also increase. At this upper contact, brown to transparent, medium to coarse crystalline selenite is also relatively abundant and typically occurs as bands, 2-10 cm thick, or as mottles (Plate 5). Clear, colourless selenite is common as coarse crystals in veins and fractures.

The interbedded facies (3a and b) are unique to the Cheepash River study site. These facies appear to occur where the massive gypsum facies (1a) should usually occur, and they can also overlie the gypsum breccia facies (2). The banding or bedding in these facies can be quite persistent along the length

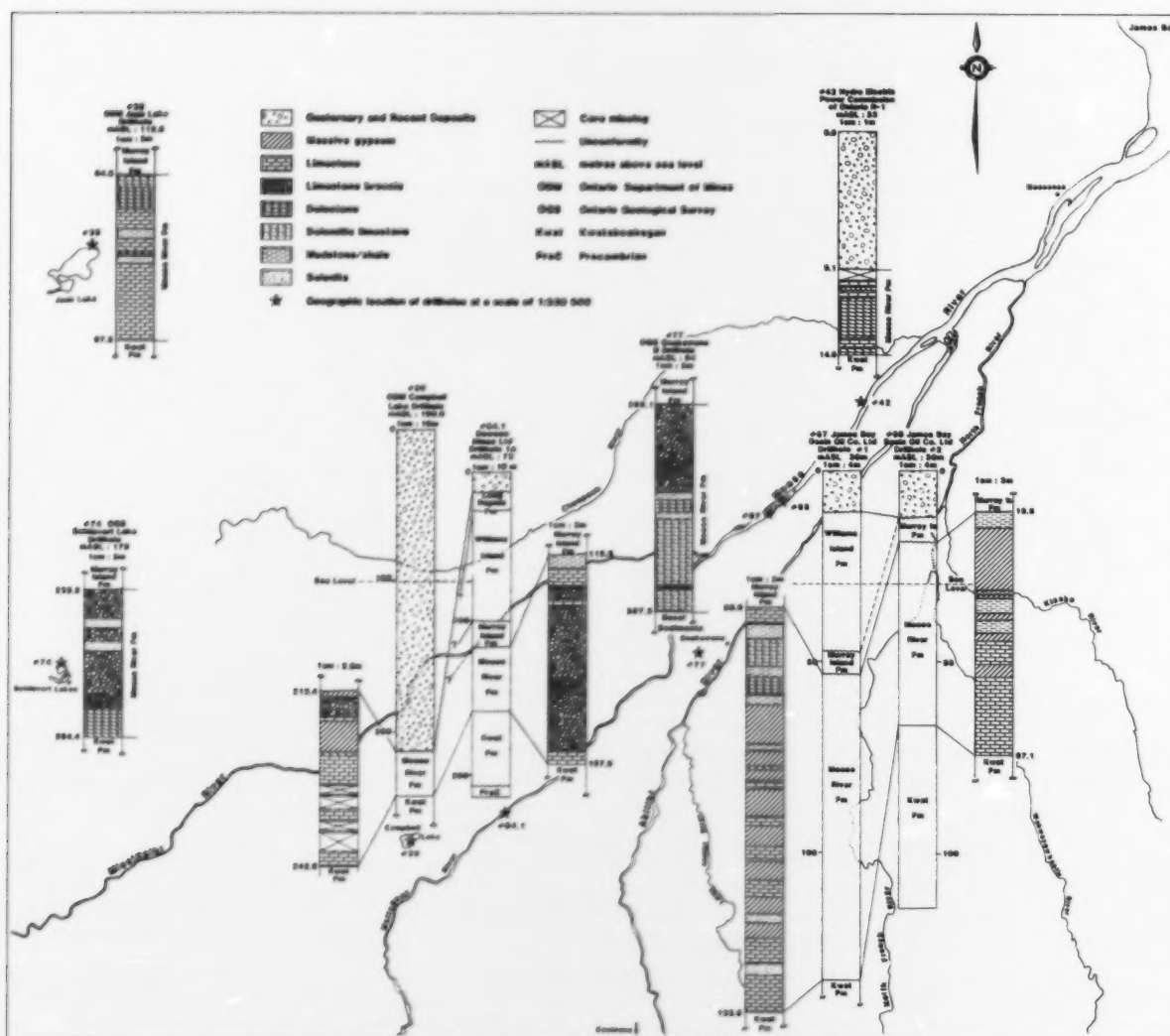


Figure 5:
Subsurface Geology of the Moose River Formation, Moose River Basin.

of the outcrop, and can also grade into the massive white gypsum facies. The banding and laminations can be quite warped and deformed (as shown in Plate 2) and some outcrops have cross-cutting dikes of gypsum and limestone breccia.

The gypsum breccia unit is a conspicuous unit at all three outcrop sites. It is most spectacular on the Moose River where very large blocks of gypsum, limestone, and selenite (up to 4 m x 6 m in diameter - average 0.5 m) are present in a matrix of fine to medium grained aggregates of gypsum, carbonate and argillaceous material. In some outcrops of gypsum with a well developed chickenwire mosaic texture, small, black flecks and laminations of bituminous or carbonaceous material can be seen (2 mm to 5 mm in size). Anhydrite was not identified in

any outcrops, although thin seams were identified in the Schlievert Lake (#74), Campbell Lake (#39), Jaab Lake (#38), and James Bay Basin Oil (#67) drillholes.

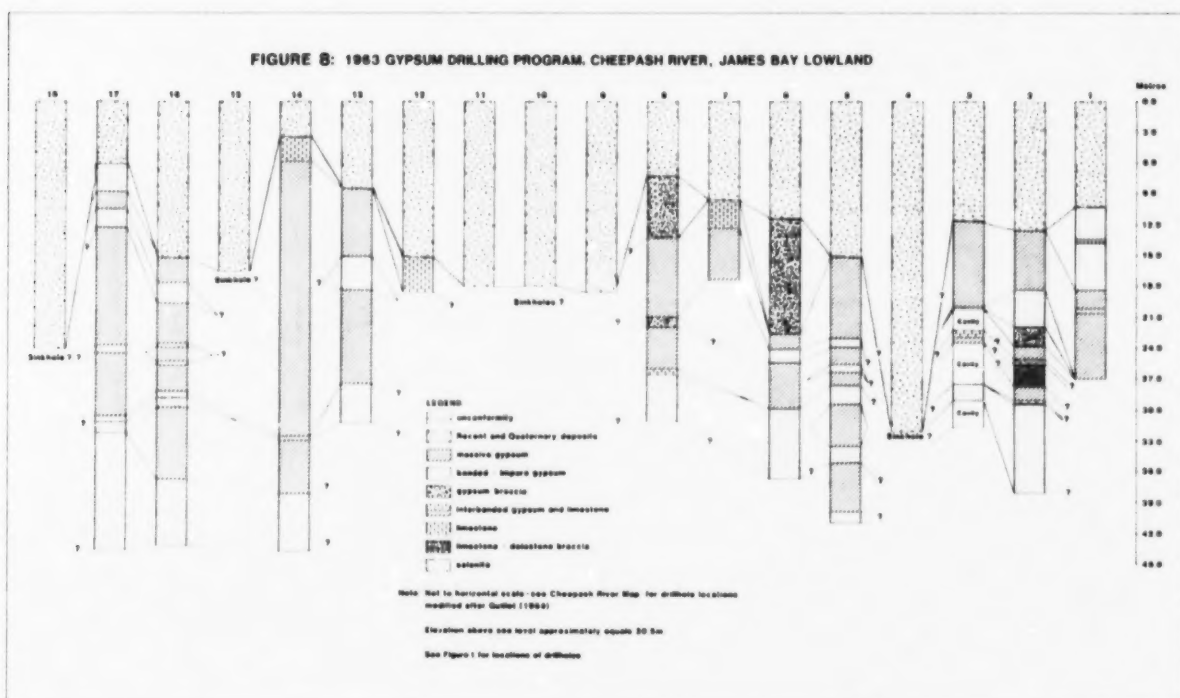


Figure 6:
1963 Gypsum Drilling Program, Cheepash River, James Bay Lowland.

Cheepash River

Exposures of gypsum occur over a distance of approximately 9 km on the Cheepash River, commencing about 16 km upstream (north-westerly) from the Ontario Northland Railway bridge (Figure 7). Outcrops of gypsum are discontinuous on both sides of the river, with section thicknesses ranging from 0.5 m to 12 m (average 3 m). The dominant lithological unit in these exposures is a massive snow-white gypsum with a chickenwire mosaic texture. It is typically massive, medium to finely crystalline, with banding prominent in some sections. The bands consist of alternating massive gypsum and dark brown to clear, coarsely crystalline selenite. Limestone clasts and impurities are also common. Where the massive white gypsum dominates the section, the surface can be very smooth and scalloped, or rounded. The face of the outcrop can be undercut by dissolution. Along the south side of the Cheepash River, an 18 hole drilling program was carried out in 1963 to delineate the gypsum deposits (Figure 6). This program proved the existence of the gypsum to approximately 40 m below the surface. As was mentioned earlier, the upper surface of the Moose River Formation in this area is very scalloped and eroded, probably due to a combination of karstification and glacial scouring.

Moose River

Exposures of gypsum occur on the Moose River, northeast of the Ontario Northland Railway bridge at the community of Moose River Crossing (Figure 8). The north bank outcrops extend east for approximately 4 km, and the south bank exposures extend east for approximately 3.5 km. A second outcrop of gypsum, approximately 1 km in length, occurs 11 km east of the railway bridge on the south bank of the Moose River.

The Moose River gypsum exposures consist predominantly of two units: massive to banded pure gypsum overlain by gypsum breccia. In the Moose River outcrop sites, a thin (< 1 cm) lamina of green, glauconitic gypsum consistently appears at the top of the gypsum unit, 3-10 cm beneath the breccia unit. It is quite a persistent marker bed and can be traced for considerable lengths along the outcrops. It was not identified at the Cheepash River or Gypsum Mountain study sites. Outcrop exposures of both units range in thickness from less than 0.5 m to 9 m, with an average thickness of 2.5 m. The lower gypsiferous unit typically consists of medium to finely crystalline, massive, white gypsum, with a chickenwire mosaic texture. The colour of the gypsum varies through white, orange, pink, brown, and grey. The massive gypsum unit in some exposures grades into an interbanded unit of dark brown selenite and white gypsum. Some outcrops of massive white gypsum have abundant, medium to finely crystalline, dark brown selenite eyes, which gives them a distinctive appearance.

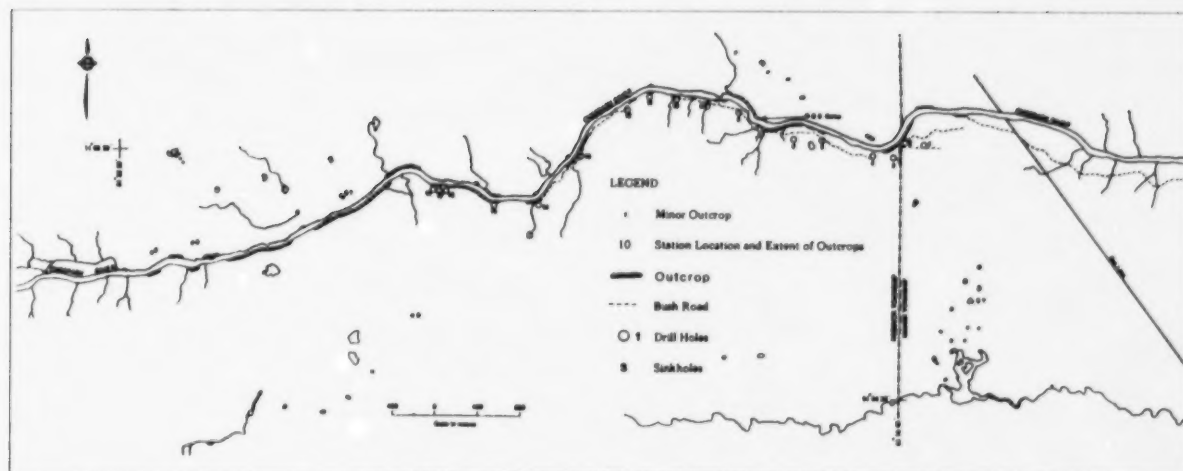


Figure 7:
Cheepash River Study Area.

A portion of the Moose River gypsum exposures (about 1.5 km of exposure on the northwest bank, northeast from the Ontario Northland Railway bridge) was identified an Area of Natural and Scientific Interest (ANSI) by the Ministry of Natural Resources (MNR) for its many varieties of gypsum, and at a minor scale, karst topography. This same site has now been also officially designated (January 1989) by the MNR as part of the Missinaibi Provincial Park, a designation which prohibits any mineral development in the indicated area. However, development outside the boundaries could be carried out.

Gypsum Mountain

Southeast of the Moose River gypsum exposures is an area called Gypsum Mountain (Figure 9), which lies between the Abitibi and North French Rivers. The area is less than 8 m above the level of the surrounding muskeg, but due to improved drainage in the area, a varied and substantial growth of trees has developed, giving the area an appearance of a "mountain-like" setting. Today the site is identified as an Area of Natural and Scientific Interest (ANSI) by the Ontario Ministry of Natural Resources due to its unique karst topography and natural gypsum bridges which span the small streams and ponds. This designation will permit resource development only if the natural and scientific features are maintained.

The area covers approximately 5 km², and can be most easily accessed by helicopter. For this study, an area of approximately 1 km² was mapped. The gypsum at Gypsum Mountain is dominantly massive, white, and medium to finely crystalline, with thin beds and laminae of brown limestone present in some sections.

Wakwayowkastic River

Several low outcrops of gypsum occur over a one kilometre stretch of the Wakwayowkastic River—about 10 km above the junction with the North French River and about 32 km southeast of Moose River Crossing. Outcrops are restricted to the east bank of the river and form low, smooth exposures. A thickness of approximately 2 m of gypsum is exposed in the sections, and consists of white, finely granular, massive gypsum with traces of dark impurities in the form of crenulated laminae.

2.3 Geochemistry

A total of 115 samples were submitted for chemical analysis. Each sample was initially analyzed semi-quantitatively for 46 elements (spectrographically). Each sample was further analyzed quantitatively for SiO₂, Al₂O₃, CaO, MgO, Na₂O, K₂O, Fe₂O₃, MnO, Cr₂O₃, P₂O₅, TiO₂, LOI, free moisture, CO₂, total C, Cl, F, S, and U (see Appendix 2 for geochemical data). The chemical analyses were carried out by Lakefield Research, in Lakefield, Ontario. The weight percentages of gypsum, anhydrite, and carbonate calculated from the whole rock analyses are summarized below. (The method of calculation is also given in Appendix 2)

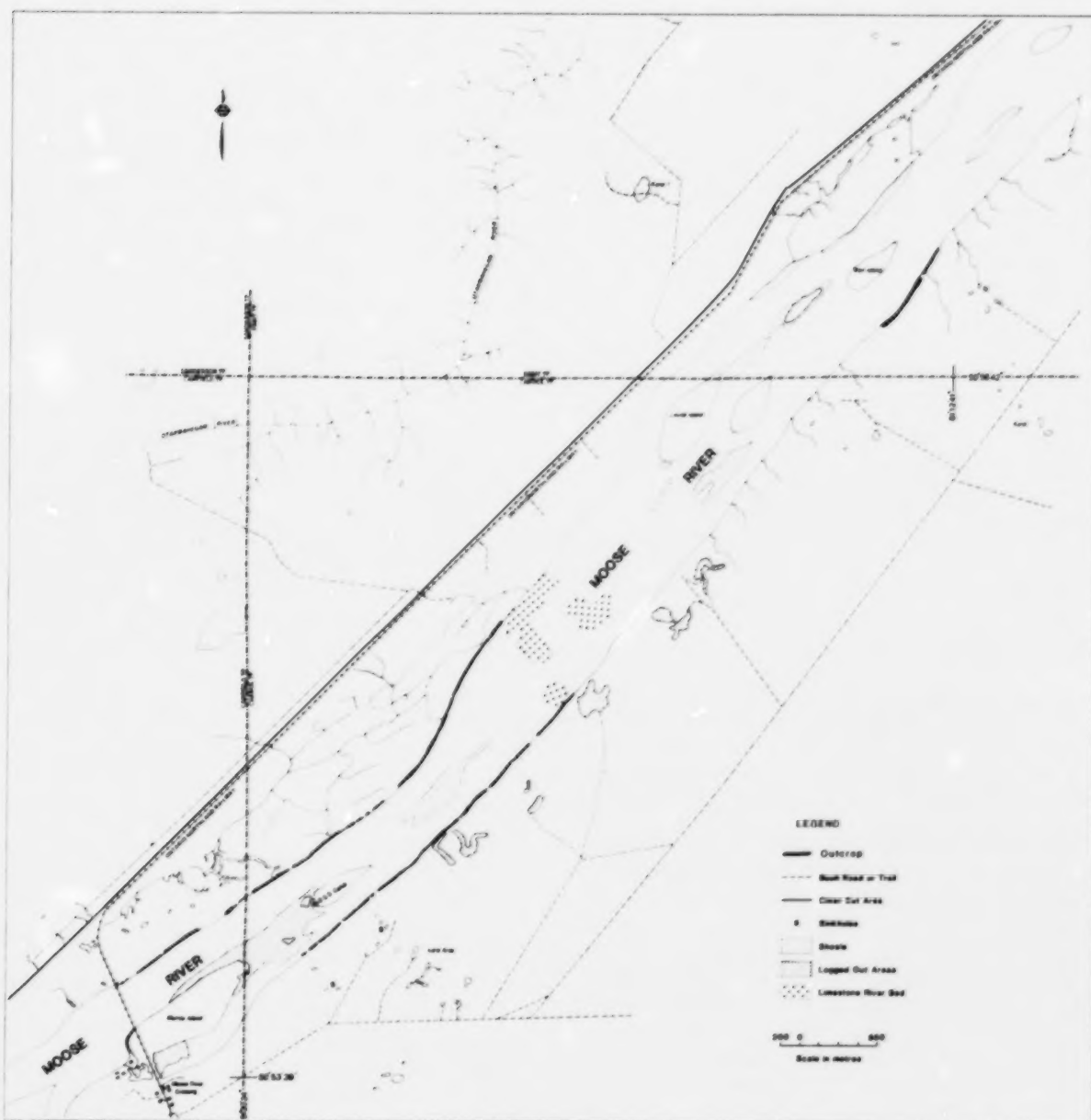


Figure 8:
Moose River Study Area.

	Moose River		Cheepash River		Gypsum Mountain	
	Massive	Banded	Massive	Banded	Massive	Banded
Gypsum						
Mean	96.3	96.6	96.7	96.4	96.8	95.0
Std Dev	1.6	2.3	2.8	2.2	1.3	
Range	92.5- 99.2	92.4- 100.0	84.3- 100.6	88.2- 99.9	95.4- 98.0	
Anhydrite						
Mean	0.2	0.9	0.8	1.5	0.8	0.0
Std Dev	0.7	1.6	1.2	1.8	1.1	
Range	0.0- 2.9	0.0- 4.3	0.0- 5.0	0.0- 7.7	0.0- 2.1	
Carbonate						
Mean	2.9	2.9	2.7	2.6	2.2	3.5
Std Dev	1.4	2.1	2.8	1.6	1.8	
Range	0.7- 6.1	0.2- 7.1	0.1- 15.7	0.3- 7.5	0.8- 4.2	
# of samples	19	14	42	36	3	1

Values for NaCl from the study sites range from 16 ppm to 560 ppm. These compositions support and confirm the previously determined apparent "high purity" of the Moose River Basin gypsum deposits and suggest approximately equal purity across all sites sampled.

2.4 Summary

Outcrops and widely spaced drillholes indicate that high concentrations of gypsum occur over potentially minable thicknesses within a 1200 sq km area of the Moose River Basin in northeastern Ontario. Geochemical analysis of 115 outcrop samples of massive to banded gypsum beds across the area indicates a relatively uniform composition in excess of 96% gypsum with minor amounts of carbonate and anhydrite. From a development perspective, the most accessible gypsum resources occur along the Moose River northeast of Moose River Crossing, adjacent to the Ontario Northland's railway line which runs from Cochrane to Moosonee.

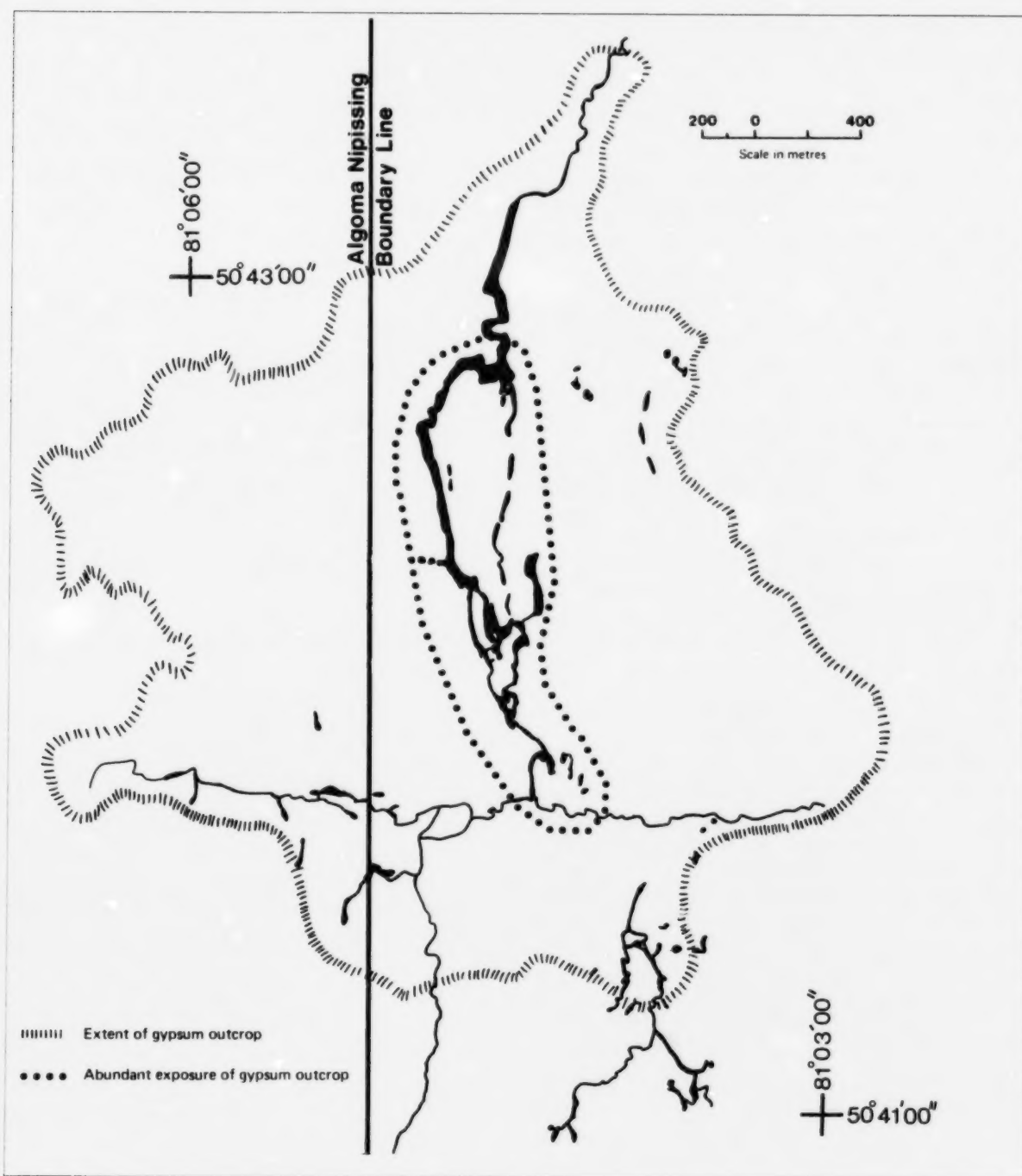


Figure 9:
Gypsum Mountain Study Area.

3. Process Technology

HIGH PURITY GYPSUM IS GENERALLY DEFINED AS BEING IN excess of 90% calcium sulphate dihydrate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. In practice, a purity of approximately 97% is generally required. When calcined, the dihydrate is converted to the hemihydrate, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$, known as plaster of Paris or stucco, or anhydrite, CaSO_4 , depending upon the control and mix of the calcination vessel variables of temperature, retention time, pressure, and nature of atmosphere.

Gypsum is a soft rock and is generally obtained by open pit mining or shallow underground mining operations. In general, gypsum mines are relatively small in comparison to metalliferous mines. The technology and scale of operations for gypsum production closely approximates that of crushed stone and aggregate production in terms of open pit mining methods. Underground mining operations resemble low volume underground coal and potash mines in terms of mining techniques and equipment. Typical North American underground gypsum mines operate on a room and pillar method. There is some trend to the use of continuous mining methods as developed in large potash mines and in the highly mechanized coal mines of the U.K. and Europe.

In the manufacture of gypsum products, raw material gypsum is ground to a maximum of approximately 18mm size and dried to remove surface water. A rotary kiln-type dryer is typically used for this step. After drying, the crude gypsum is further ground to a fineness of approximately 90% passing a 100 mesh screen. The crude material is then calcined by a variety of methods to produce a powder with uniform physical and chemical properties. The gypsum raw material should be of uniform and high purity in terms of the calcium sulphate dihydrate content. Raw materials in excess of 90% $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ are generally required to produce finished products with the desired properties.

Calcination of the gypsum raw material results in the loss of three-quarters of the water of hydration. The resulting hemihydrate, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$, is known as stucco or plaster of Paris. The calcination reaction is sensitive to the amount of heat and the partial pressure of water encountered in processing. If the reaction is conducted at atmospheric pressure and there is no saturated steam present (the typical reaction conditions), a hemihydrate product called beta stucco is produced. Further calcination results in the removal of the residual water of hydration and the formation of a soluble beta anhydrite. The beta anhydrite readily rehydrates to the hemihydrate if exposed to moisture. Beta stucco is the material used in the production of gypsum wallboard. Beta stuccos and anhydrites are generally characterized by a somewhat spherical shape with an open or disordered crystal structure caused by the rapid or violent removal of water from the crystal matrix.

The water demand or use consistency of beta stuccos, and thus the strength of the cast, can be changed through the use of various metallic salts or the use of double calcination. The addition of small amounts of soluble salts such as NaCl or CaCl_2 to the kettle feed increases the vapour pressure within

the kettle. The resulting stucco is called aridized stucco. It has a lower water demand than regular kettle stucco, and is thus stronger. However, the presence of the hygroscopic (water-absorbing) salts prevents the use of aridized stucco in some applications.

Another method of producing a strong beta stucco is to introduce water into the hot calcined mass of gypsum to reduce the temperature of the gypsum below the boiling point of water. The gypsum mass is then reheated to drive off the excess water. The resulting stucco has stabilized setting and water demand properties, and a lower use consistency than aridized stucco. This product is called double calcined stucco.

If the reaction is carried out at a temperature above 120°C (preferably 150°C) and under a saturated steam atmosphere, the resulting hemihydrate product is called alpha stucco. Calcination at higher temperatures results in the formation of the alpha anhydrite. Alpha anhydrite is a more insoluble compound than the beta anhydrite. Alpha stucco is the basis for the production of high quality industrial plasters, gypsum cements, and fillers. The alpha stuccos and anhydrites are generally characterized by a more acicular or needle-like shape and a less open, more ordered crystal structure.

Gypsum plasters and cements are differentiated on the basis of the size and shape of crystals formed during the manufacturing process. The crystal size and shape, in turn, affect the water solubility and the amount of water (or use consistency) required to make a workable slurry. Thus, the end-uses of the gypsum are affected. In general, low use consistency stuccos are preferred over stuccos requiring more water. Plasters generally require 60-75 grams of water per 100 grams of stucco while cements generally require 20-45 grams of water per 100 grams of stucco to produce a workable slurry.

There are several technologies available for the production of alpha and beta stuccos and anhydrites. These are described in Appendix 3.

4. Gypsum Markets

4.1 Uses and Specifications

THE USES OF GYPSUM AND PLASTER OF PARIS ARE BASED ON the ability of the hemihydrate to readily absorb water and revert to the dihydrate form and harden. In addition, the ability to precisely control the rate of rehydration and the amount of linear expansion upon setting are very important properties. The set time for stucco can be controlled rather precisely from under 4 minutes to over eight hours with the use of set accelerators and set retarders. Linear expansion, which is normally 0.2%-0.3%, can be varied through the use of additives from approximately 0.03% to over 1.2%. Secondary properties of importance include gypsum's fire resistance, excellent thermal and hydrometric dimensional stability, good compressive strength, and neutral pH.

Gypsum plasters and cements possess extreme ranges in strength, absorption, and density. Compressive strengths can range from the weakest chalk to four times greater than concrete. Absorption can equal that of a rigid sponge or an impervious surface that sheds water. Density can vary from popcorn to stone. These ranges are obtained by selecting the appropriate plaster/cement, then controlling the amount of mixing water.

Plasters and gypsum cements readily blend with aggregates (minus 10 mesh) to achieve special properties. Some examples of such aggregates are talc, clay, perlite, sand, vermiculite, glass/polymer fibres, iron oxide, set-time control additives, and pigments. These blended materials are used to produce lightweight plasters and gypsum cements, sound attenuation plasters, heat resistant plasters, high impact strength plasters, coloured plasters, etc. for both construction and industrial uses.

High purity gypsum and plasters find application in a very broad range of industries. Some of the applications are listed below:

- dental plaster for casts for plate work
- surgical plaster for orthopaedic casts
- bedding plaster to support plate glass during polishing
- moulding plaster for foundries and ceramics manufacturing plants
- building plasters:
 - base coat
 - veneer coat
- excipients, fillers, binders, and diluents for pharmaceutical preparations
- fillers and extenders for cosmetic preparations
- food additives
- filler for pulp and paper manufacture
- substitute for salt cake in glass manufacture
- fillers and extenders for plastics manufacture
- road repair and oil well casing cements

Individually, these applications are generally low in volume. The end-use requirements for the gypsum tend to be rather specific in terms of particle size and shape, particle size

U.S. Gypsum Demand

- Agriculture
- ▨ Cement
- ▤ Fillers & Miscellaneous
- ▩ Industry & Building Plaster
- Prefabricated Products

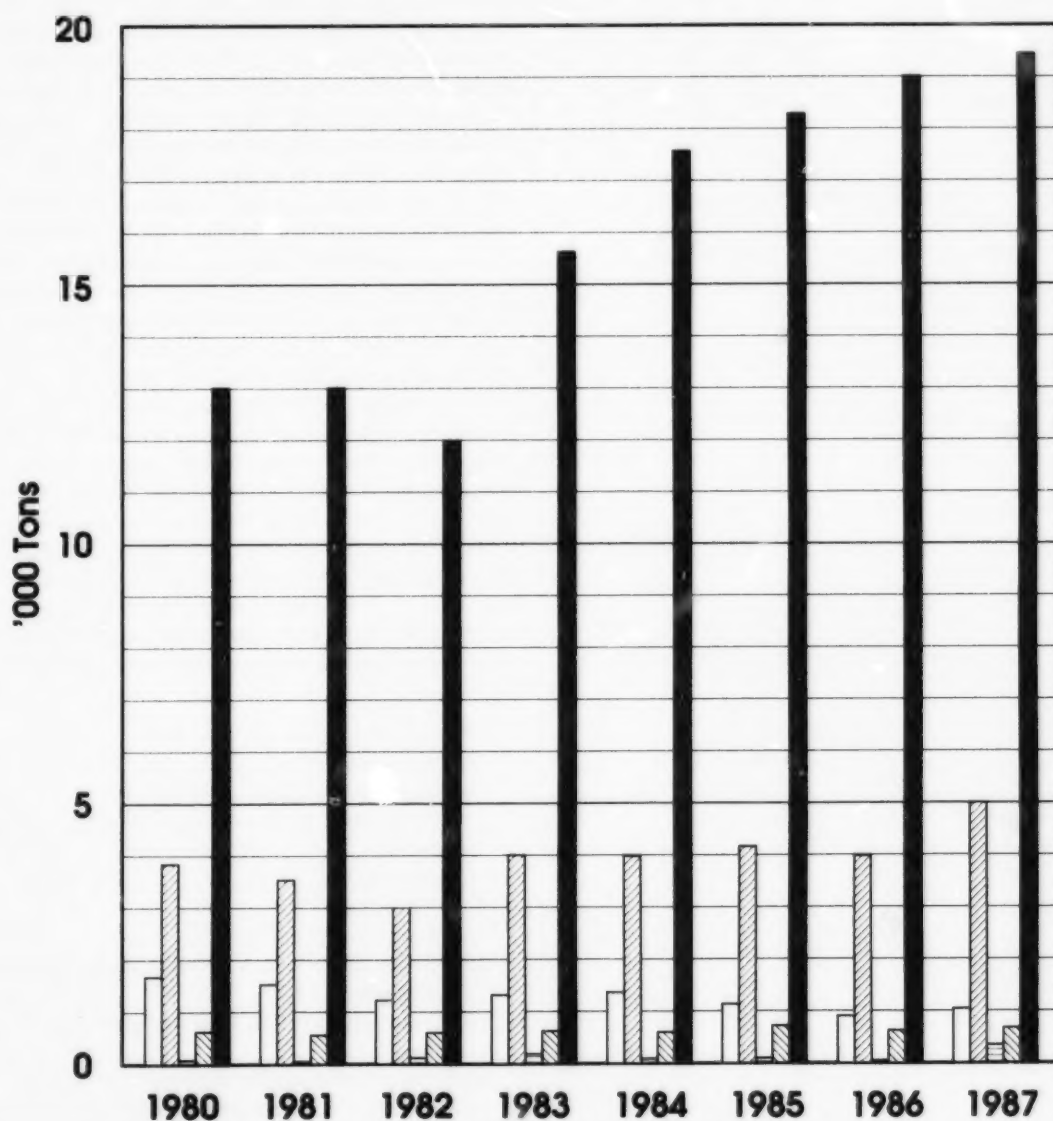


Figure 10:
Source: U.S. Bureau of Mines

distribution, use consistency and expansion, and compressive strength. Colour and chemical purity are important considerations in many of the markets. Finally, while not all of the listed applications require the use of high purity gypsum, purity can play an important part in the selection and use of gypsum versus competitive materials in some of the listed applications. Because of these factors, gypsum suppliers often have to provide specific grades for each market and/or customer. The high purity gypsum business thus has more of the characteristics of a chemical specialty business than a commodity business.

It should also be noted that high purity gypsum can be used in the manufacture of gypsum wallboard. Given a readily accessible deposit and favourable transportation and market economics, there is no constraint to the use of high purity gypsum in commodity items such as wallboard. In fact, the Nova Scotia gypsum industry was developed on the use of relatively high purity gypsum (>90% purity) for wallboard manufacture.

Data on the size of the North American market for high purity gypsum are relatively scarce. The available data include information on use of gypsum in wallboard production, cement, and agriculture, as well as for use in fillers and in building and industrial plasters. The following sections detail information on gypsum demand by major end-use.

Wallboard

Figure 10 provides data on U.S. gypsum demand by major end use for the 1980-1987 period. As can be seen, wallboard production accounts for the largest proportion of total demand. In 1987, requirements for gypsum in wallboard production were 19.4 million tons. Gypsum for use in wallboard production is generally priced at less than \$10.00 per ton, FOB mine site. Figures 11 and 12 provide additional detail on wallboard production and prices in the United States during the 1980-1987 period. The market is dominated by regular gypsum and Type X (fire resistant) board in terms of volume, while specialty gypsum boards such as predecorated and moisture resistant gypsum board command premium prices.

Other building board products manufactured from gypsum include gypsum particleboard and gypsum fibreboard. Gypsum particleboard is a new development based on the use of gypsum stucco as the cementing agent for hammermilled wood fibre. The product has physical and mechanical properties intermediate between gypsum wallboard and particleboard. It was developed in Europe as a replacement to urea-formaldehyde bonded particleboard and is used in floor underlayment and interior wall applications. There are two plants in Europe producing the product. Gypsum fibreboard is a building board product based on gypsum stucco and ground waste newspaper. The product is slightly stronger than gypsum wallboard. It is currently only produced in Europe, principally Germany, and is used in floor underlayment and interior wall applications. Two plants, one in Nova Scotia and one in Rhode Island, are scheduled to begin operations in 1990.

There are no industry wide specifications for gypsum used in wallboard manufacture. Instead, each wallboard manufac-

turer sets its own requirements. In general, however, crude gypsum of at least 70% purity is required to manufacture an acceptable product at a competitive cost. Some of the more important considerations in the selection of a crude gypsum raw material include the following:

- calcium sulphate dihydrate content
- free water content
- SO₃ content
- pH
- alkali metal ion content
- total water soluble salt content
- particle size

The requirements respecting these parameters can vary considerably. Wallboard producers with captive sources of supply can accept fairly wide variations in the quality of their raw materials. Purchased gypsum, on the other hand, tends to have rather strict limitations placed upon its chemical and physical specifications. For example, Atlantic Gypsum, an independent wallboard manufacture in New Jersey has the following specification:

- 92% CaSO₄·2H₂O content
- total soluble salts <200 ppm
- free moisture content 2% max.

Atlantic Gypsum indicates that the minimum acceptable gypsum content would be 85%. Many of the same restrictions apply to the use of by-product gypsum by the major wallboard producers. Data provided by USG and Domtar with respect to by-product gypsum use indicate the following:

	USG	Domtar
CaSO ₄ ·2H ₂ O content	>92 wt. %	>95 wt. %
free moisture content	<10 wt. %	<10 wt. %
CaSO ₃ ·1/2H ₂ O content	2 wt. % max.	<0.5 wt. %
Na ⁺		<75 ppm
Cl ⁻		<75 ppm
Mg ²⁺		<100 ppm
pH		6.5 - 8.0
soluble chlorides	120 ppm max.	
total water soluble salts	600 ppm max.	
particle size	> 20 µm	<4,000 Blaine
fly ash	1.0 % max	

It is likely that by-product gypsum will find increasing use in wallboard manufacture in coming years. Regulations respecting acid gas emissions from thermal power plants, metallurgical plants and chemical plants are becoming more strict. The most popular technologies employed to meet the new pollution regulations involve the use of limestone or lime gas scrubbers, and the consequent production of large volumes of by-product gypsum. In fact, the potential for production of by-

Prefabricated Products U.S.

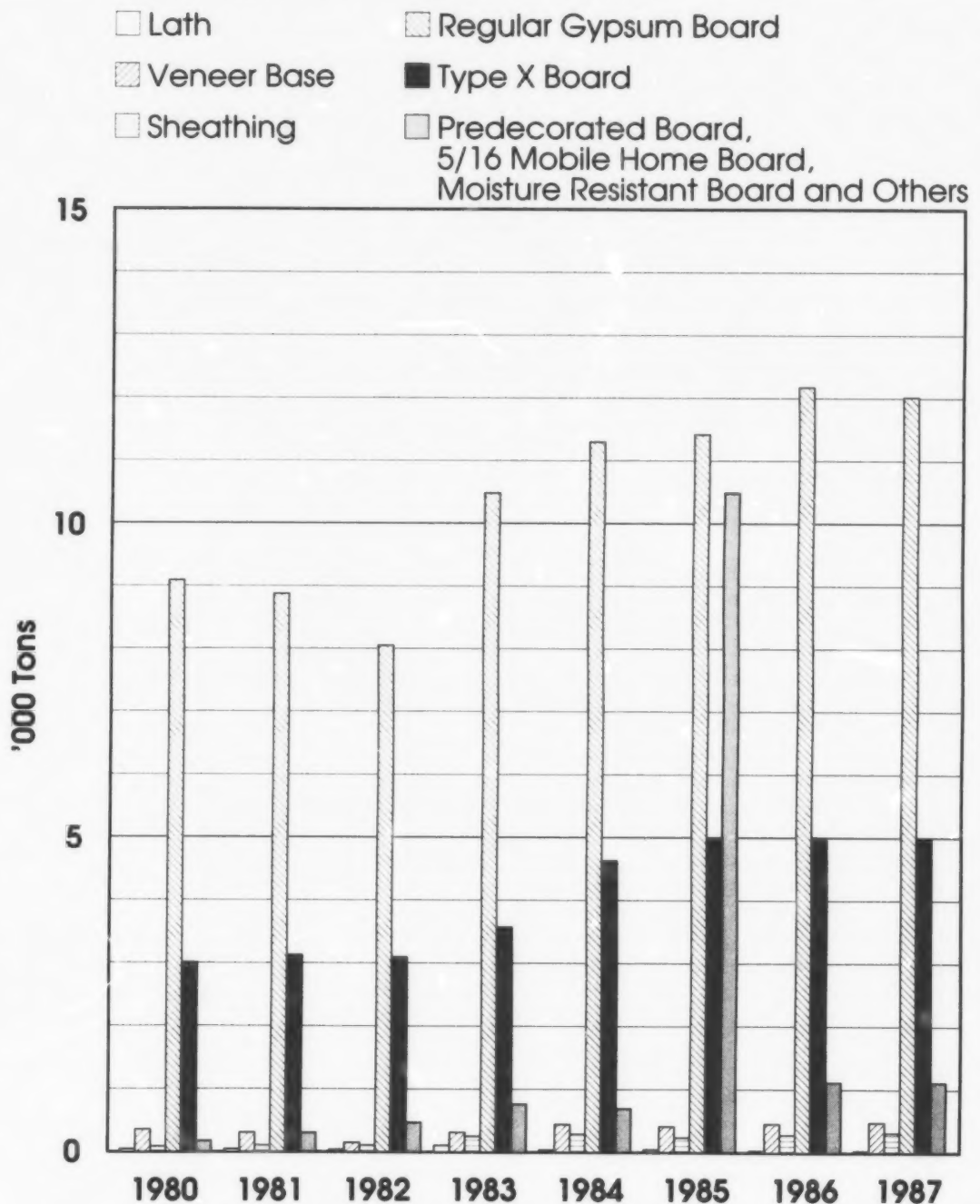


Figure 11:
Source: U.S. Bureau of Mines

product gypsum greatly exceeds current North American demand for gypsum for all uses. It can be expected that this new raw material source will have an impact on the use and price of natural gypsum for wallboard manufacture.

Cement and Agriculture

Other markets for gypsum show less volatility in terms of demand. Cement and agricultural uses dominate the remaining markets, as can be seen from Figure 10. Cement producers blend crude pulverized gypsum (+ 6mm) with clinker to produce a finished cement generally containing approximately 4.5% gypsum by weight. The gypsum is used as a set control agent. There are no significant restrictions on the purity of gypsum used in the cement, although high levels (>10%) of anhydrite are undesirable. One cement producer has established the following specifications for gypsum:

- #360 crude gypsum/anhydrite rock
- 65% gypsum, $\pm$ 5% anhydrite
- 52% $\pm$ 2% SO₃
- 2% retained on a 4 mesh screen

There is no readily available or acceptable substitute for gypsum in portland cement manufacture, although by-product gypsum derived from the neutralization of phosphoric acid wastes or the desulphurization of coal fired power plant exhaust gases can be equally as effective. In fact, there may be substantial displacement of natural gypsum by synthetic gypsum in this application if sources are developed near cement plants. In 1987, the U.S. demand for gypsum in cement manufacture was 4.99 million tons at an average price of \$10.62 per ton. Demand for gypsum for cement manufacture is expected to parallel growth in cement production.

Application of gypsum to soils for agricultural purposes generally does not require a high purity gypsum. The specifications for gypsum used in agriculture primarily relate to the degree of fineness of the material, rather than the chemical composition of the gypsum. Gypsum combines with potassium aluminum silicates in the soil to render the potassium in a soluble form for use by the plants. Gypsum is useful in reducing the sub-soil acidity and thereby reducing the toxicity of aluminum in lateritic soils. Gypsum also provides soils with a source of both calcium and sulphur trioxide and helps to break up hard soils to allow better aeration, water penetration, and retention. Gypsum is also used as a conditioner and stabilizer for manure used in mushroom growing.

The southern United States is the principal area where gypsum is applied. The red, lateritic soils (developed from weathering) of the region are deficient in soluble potassium, calcium, and sulphur; they tend to be hard crusting. Soils for peanut and citrus crops are most subject to treatment by gypsum. The gypsum producers recommend typical application rates as follows:

- alfalfa and clover 900 kg/acre at seeding
- hay and grasses 90 - 270 kg/acre at seeding, plus 225 - 450 kg/acre after cropping
- wheat 135 - 450 kg/acre by drilling or broadcasting at seeding
- corn 225 - 450 kg/acre during ground preparation or drilled in at time of seeding
- potatoes 225 - 450 kg/acre during ground preparation or drilled in at time of seeding
- peanuts 225 - 450 kg/acre during ground preparation or at time of planting
- citrus trees 45 kg/tree

There is significant competition from by-product gypsum for the agricultural market. Data from the U.S. Bureau of Mines indicate that approximately 76% of gypsum used in agriculture in the United States in 1987 was by-product gypsum derived from phosphoric acid production and flue gas desulphurization. It can be expected that by-product gypsum will continue to displace natural gypsum in this application due to cost and availability factors. In 1987, use of gypsum for agricultural purposes in the United States was reported to be approximately 1.1 million tons at an average price of \$16.68 per ton.

USG markets four grades of agricultural gypsum. These are:

- regular grind
- coarse grind
- 420 landplaster
- #1 agricultural gypsum

The products differ only in the degree of grinding to which they are subjected. The other major gypsum producers also produce similar ranges of agricultural gypsum.

Chemical Uses

Calcined, specially sized plaster is used to a limited extent as a chemical additive to ceramic glazes. The gypsum supplies neutral, slightly soluble calcium and sulphate sulphur to the glaze.

Uncalcined gypsum is used as a glass batching material in combination with soda ash. Depending upon the proportions of gypsum and soda ash in the batch, gypsum can replace part or all of the salt cake. The gypsum is used as an oxidizing and fining agent and to prevent "salt water scumming" while retaining the fluxing property of the salt cake. The use of gypsum as a source of sulphur in this application is increasing. The gypsum acts as a cheap substitute for the traditional barium sulphate used as a source of SO₂ gas, which aids in clearing up the glass and in giving added brilliance. Relatively pure gypsum must be used as precise control of iron and other metallic elements is essential in the production of clear glass. It is estimated that approximately 25,000 tons per year of gypsum is used for chemical purposes and in glass making.

Prefabricated Products U.S.

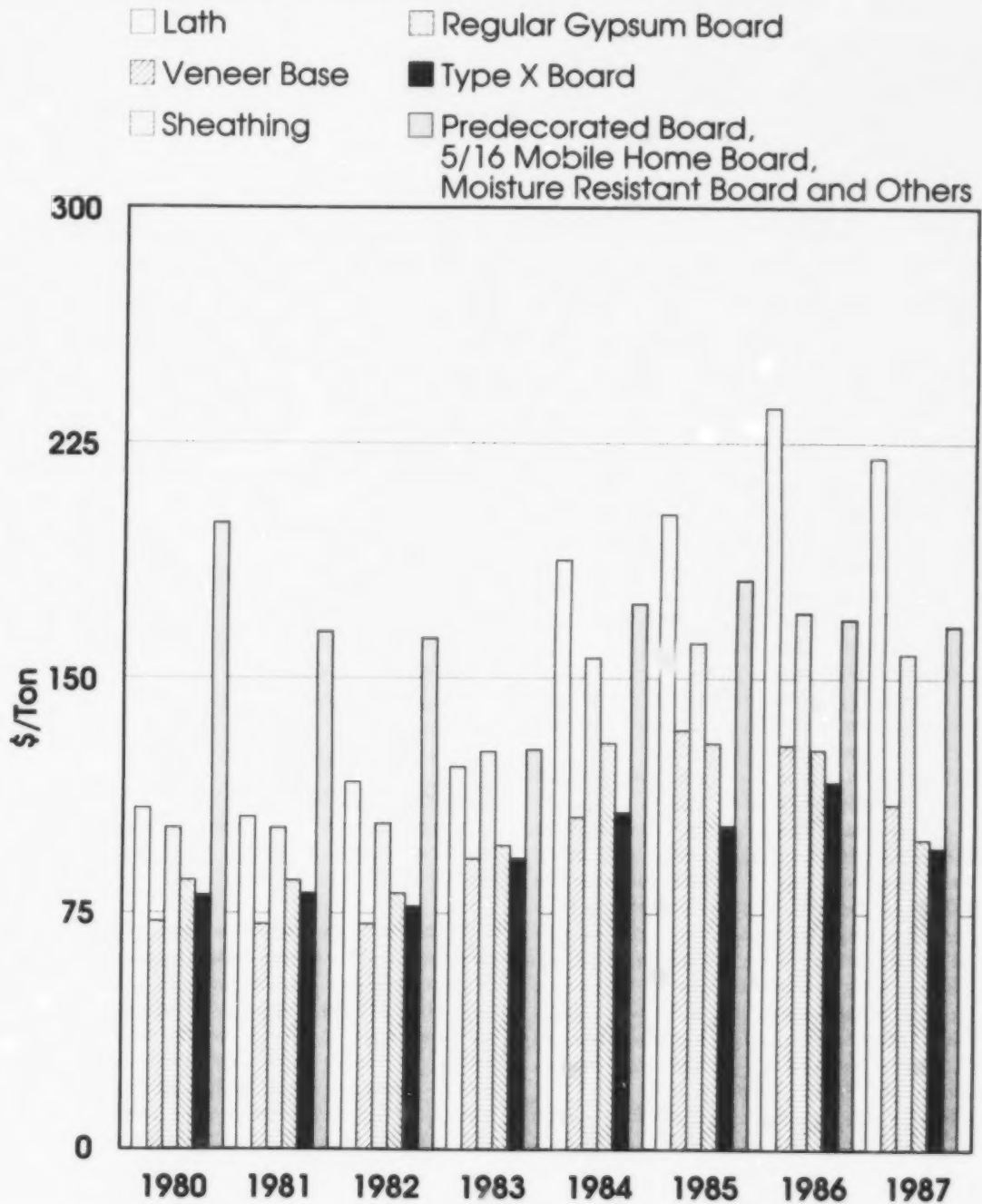


Figure 12:
Source: U.S. Bureau of Mines

High Purity Plasters

High purity gypsum plaster products fall into two general categories. These are:

- Building Plasters:
 - Regular Base Coat
 - Veneer Plaster
- Industrial Plasters and Gypsum Cements:
 - Industrial and Moulding Plasters
 - Poured Gypsum Cement and Keene's Cement

Figures 13 and 14 provide data on consumption and prices of gypsum for these uses in the United States for the 1980-1987 period. It is evident from the data that building plasters have experienced a decline in demand and that industrial plasters are experiencing a very modest increase in consumption.

Building plasters are defined by the American Society for Testing and Materials (ASTM) under the following categories:

- gypsum concrete: a calcined gypsum mixed with wood chips and/or aggregate, used primarily for poured roof decks
- gypsum neat plaster: a calcined gypsum plaster without aggregate, commonly used for gypsum plaster for base coats
- ready-mixed plaster: a calcined gypsum plaster with aggregate added during manufacture, also known as mill mix plaster
- portland cement plaster: a plaster mix in which portland cement or combinations of portland and masonry cements or portland cement and lime are the principal cementitious materials mixed with aggregate. The most common form is known as stucco and is used on exterior surfaces
- veneer plaster: a calcined gypsum plaster specially manufactured to provide high strength, hardness, and abrasion resistance when applied in thin coats over a veneer plaster base
- veneer plaster base: a gypsum board used as the base for application of a gypsum veneer plaster
- gauging plaster: a calcined gypsum plaster used with lime for a finish coat
- Keene's cement: an anhydrous gypsum plaster characterized by a low mixing water requirement and special setting properties, primarily used with lime to produce hard, dense finish coats
- moulding plaster: a calcined gypsum plaster used primarily for plaster casts or moulds, sometimes used as a gauging plaster

Building plasters are used as the base coat and finish coat for high quality residential and non-residential construction. Building plasters are primarily based on the use of beta stuccos. The plasters may have set control agents and other additives to provide for a range of properties such as quick setting, moisture resistance, etc. Base coat plasters are commonly known as the brown coat. They are mixed with sand or other

aggregate materials, and may have fibrous matter added as well. The base coat is applied to a wood, expanded metal, or gypsum board lath fastened to the studs or joists forming the interior walls or ceilings of the building. In older buildings the lath may be attached to furring strips placed at intervals in the brick work of the walls.

Veneer plasters, also known as the scratch coat, are higher quality plasters. These plasters are generally formed from higher purity gypsum materials than the base coat plasters, and are much whiter. The plasters are designed to have a higher surface hardness than the base coat plasters, and may be mixed with lime or other materials. Veneer plasters may be applied over a plaster base coat, or they may be applied over a gypsum veneer substrate. This latter form of construction is more common now than a pure two part plaster wall construction system.

Gauging plaster is a special form of veneer plaster which has a high compressive strength. It is designed to be mixed with a lime putty to provide a hard surface finish to the wall. The plaster may have set control and other additives incorporated in the formulation to provide additional properties.

Keene's cement is an anhydrous plaster characterized by a low use consistency and special setting properties. It is produced by the high (700°C) temperature calcination of gypsum in a rotary kiln. Set accelerators such as aluminum sulphate are normally added to the plaster. Keene's cement is primarily used with lime to produce a hard, dense finish coat in two part plaster constructions in areas such as bathrooms.

Construction costs using a two part plaster system are considerably higher than with gypsum wallboard. Data from the 1989 edition of Means Building Construction Cost Data show the following:

Interior Wall Construction Costs

	\$U.S./Sq.Ft.		
	Materials	Labour	Total
2 Part Plaster System, incl. metal lath, on wood studs, 3 coats	0.57	1.24	1.86
Gypsum Wallboard (1/2") on walls, standard			
no finish included	0.20	0.17	0.37
taped and finished	0.25	0.35	0.60

U.S. Gypsum Use

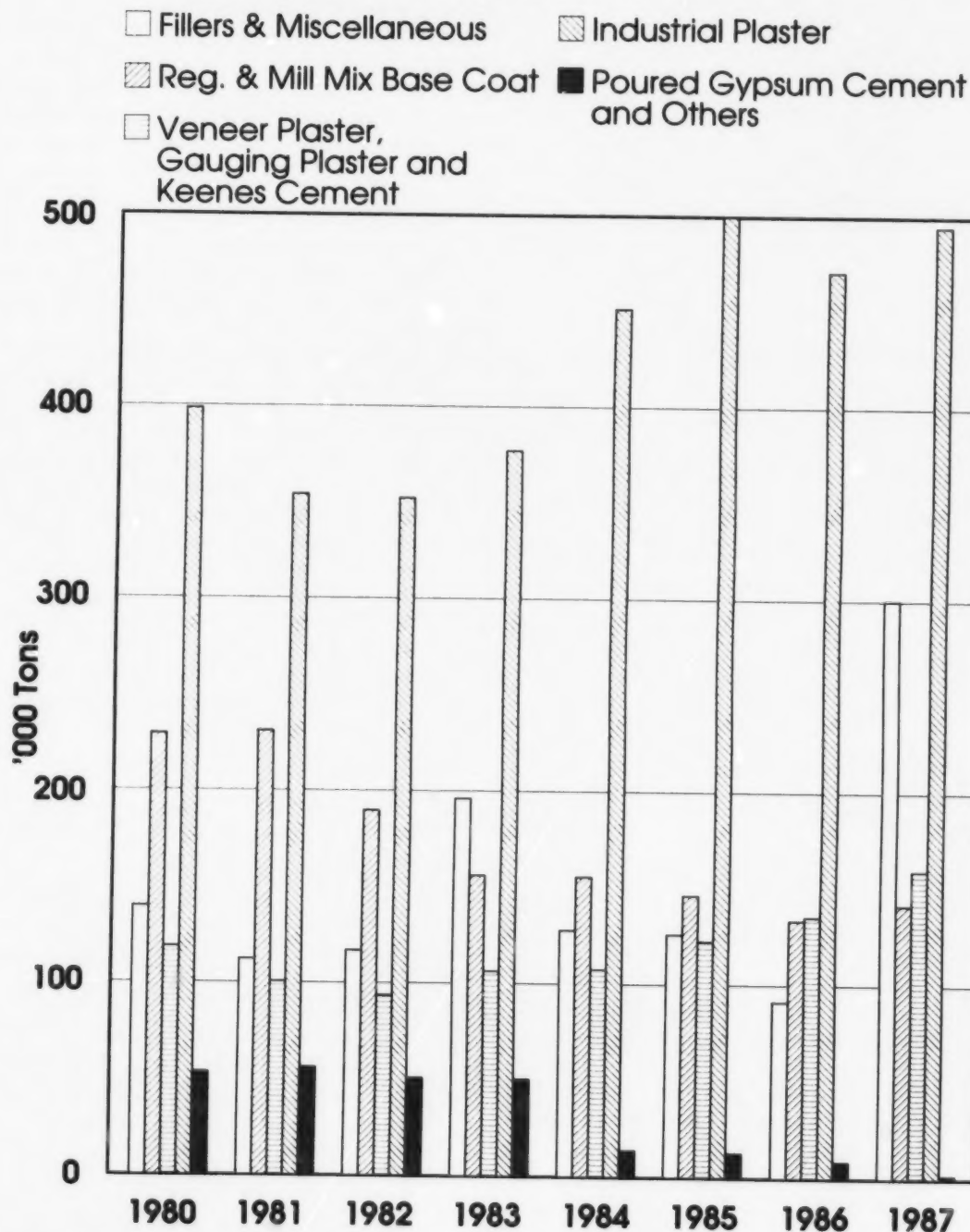


Figure 13:
Source: U.S. Bureau of Mines

U.S. Gypsum Prices

- Fillers & Miscellaneous
- ▨ Industrial Plaster
- ▤ Reg. & Mill Mix Base Coat
- Poured Gypsum Cement and Others
- ▧ Veneer Plaster, Gauging Plaster and Keenes Cement

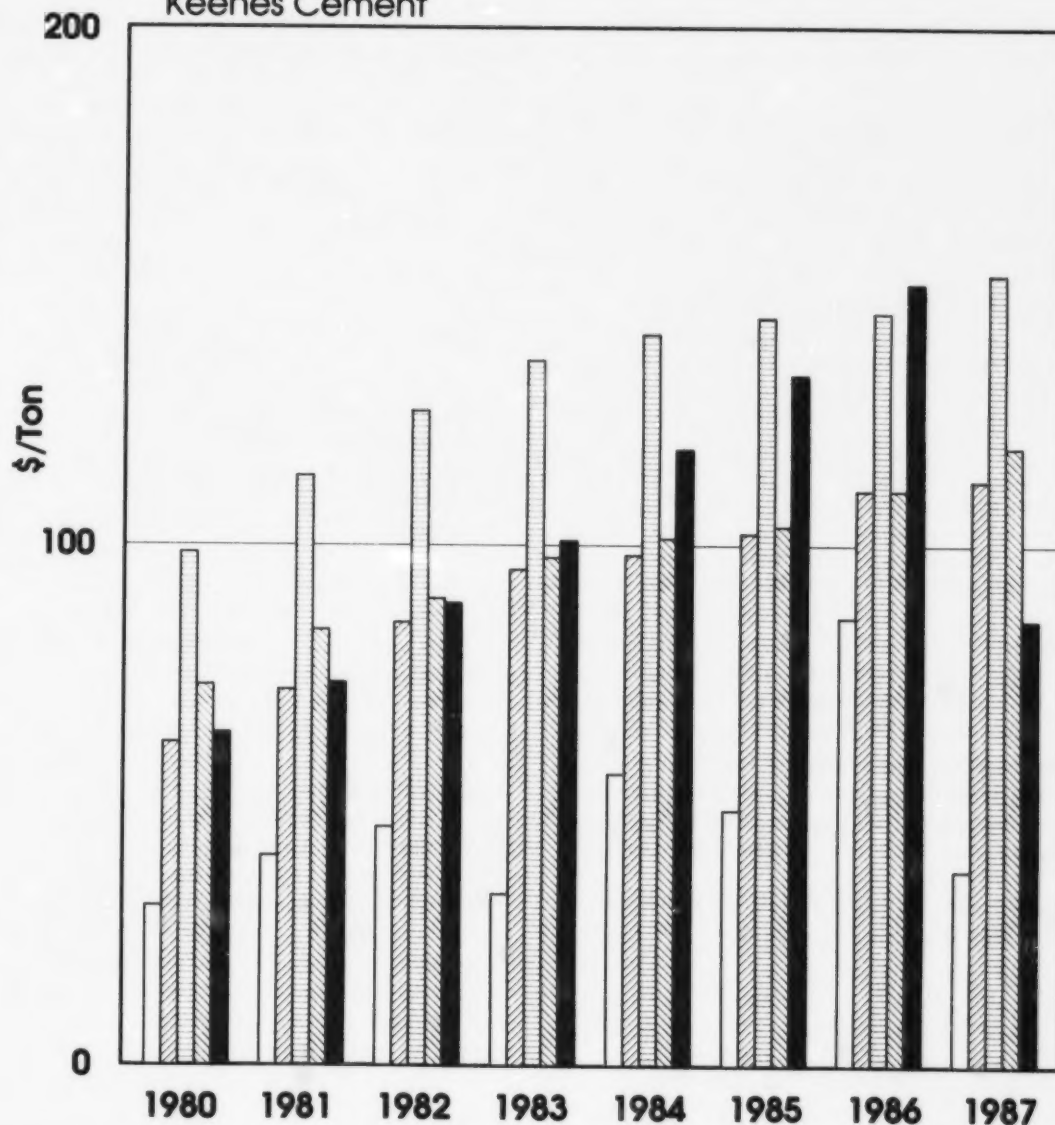


Figure 14:
Source: U.S. Bureau of Mines

As a consequence of the higher costs, the demand for building plasters is at a relatively low level. United States demand for building plasters in 1986 and 1987 was as follows:

	Tons	
	1986	1987
Regular base coat	133,000	136,000
Veneer plaster	107,000	114,000
Gauging plaster & Keene's cement	29,000	27,000
Other	7,000	-
Total	276,000	277,000

Source: U.S. Bureau of Mines, Mineral Industry Surveys

No growth is forecast in the demand for building plasters in the United States. The same situation can be expected to prevail in Canada. There will, however, always be a small demand for high quality plaster wall construction, resulting in a minimum annual demand of approximately 250,000 tons of material.

Gypsum cements are specially calcined plasters having low use consistencies and high compressive strengths. They are used as fire resistant roof decking materials, as self-leveling floor underlayments, as sound deadening materials, as road repair materials, and other applications where a combination of quick setting time and relatively high compressive strength are required. One well known form of gypsum cement is Gyp-Crete. Gypsum cements may be mixed with aggregate materials and special additives to enhance their properties. USG Corporation markets a very high compressive strength gypsum cement, Duracal, which is used as a road patching compound and another high strength gypsum cement, Envirostone, which is sold as a solidifying agent for liquid industrial waste and radioactive waste materials. The demand for gypsum cements is very low. United States demand in 1986 and 1987 was 2,000 and 3,000 tons, respectively. Demand is not expected to show any increase in the foreseeable future. Other cheaper, less labour intensive products are substituting for gypsum cements in the noted applications.

Average 1986 and 1987 producer prices for building plasters and gypsum cements were as follows:

	1986	1987
Regular base coat	\$111.94/ton	\$112.21/ton
Veneer plaster	\$153.38/ton	\$156.86/ton
Gypsum Cement	\$ 69.50/ton	\$ 82.67/ton
Gauging plaster & Keene's cement	\$127.76/ton	\$128.63/ton

Source: U.S. Bureau of Mines, Mineral Industry Surveys

Specifications for building plasters, gypsum cements, and gypsum aggregates are set by the American Society for Testing and Materials (ASTM) and the Canadian Standards Association (CSA). The specifications set minimum physical and mechanical performance standards for the products. Chemical purity standards are not set, except for the requirement that the plasters have a minimum of 85% calcium sulphate content. Table 1 details the ASTM and CSA specifications for building plasters, gypsum cements, and gypsum aggregates.

Table 1
Specifications for Gypsum Plasters and Cements
CSA and ASTM

Neat Plaster	
Setting Time	2 hr. min, 16 hr. max
Compressive strength	> 5.2 MPa
Gauging Plaster	
Setting Time	20 min. min, 40 min. max.
Compressive strength	> 8.3 MPa
Fineness	100% passing 1.4 mm sieve 60% passing 150 µm sieve
Casting and Moulding Plaster	
CaSO ₄ ·2H ₂ O content	> 85%
Setting Time	10 min. min, 50 min. max.
Compressive strength	> 12.4 MPa
Fineness	100% passing 600 µm sieve >90% passing 150 µm sieve
Keene's Cement	
Setting Time	20 min. min, 6 hr. max.
Compressive strength	> 17 MPa
Fineness	100% passing 1.4 mm sieve >98% passing 425 µm sieve >80% passing 150 µm sieve
free moisture content	<2%
Gypsum Concrete	
Setting Time	20 min. min, 90 min. max.
Compressive strength	Class A 3.5 MPa Class B 6.9 MPa
Density	Class A <60 lb/ft ³

Sieve Analysis of Aggregates for Use in Interior Plaster Canada and United States

Retained on Sieve	(% by Volume)					
	Perlite ²		Vermiculite ²		Sand ^{1,3,4}	
	Max	Min	Max	Min	Max	Min
4.75mm	0	-	0	-	0	-
2.36mm	5	0	10	0	5	0
1.18mm	60	5	75	40	30	5
600 µm	95	45	95	65	65	30
300 µm	98	75	98	75	95	65
150 µm	100	85	100	90	100	90

1. Not more than 50% retained between any two consecutive sieves.
Not more than 25% retained between 300 µm and 150 µm sieves

2. Maximum content of aggregate:

1.25 dm³/kg of plaster for use over lath bases

1.87 dm³/kg of plaster for use over porous masonry bases

Weight of aggregate:

perlite: 96 to 192 kg/m³

vermiculite: 96 to 160 kg/m³

3. Maximum content of aggregate:

1.56 dm³/kg of plaster for use over lath bases

1.87 dm³/kg of plaster for use over porous masonry bases

4. less than 5% finer than 75 µm

Maximum soluble impurities: 0.15 wt%

Maximum Na⁺ content: 0.02 wt%

Source: Canadian Standards Association
American Society for Testing and Materials

Industrial plasters are used in a variety of processes. The principal applications are in moulding processes such as slip casting ceramic bathroom fixtures, casting ferrous and non-ferrous materials, industrial models, jigger moulds, etc. Industrial plasters are also used in combination with oil well cements for cementing well casings; to assist in the binding of backfill material in mining; for mine dusting in coal mines; as bedding and leveling agents in grinding and polishing plate and optical glass; and other miscellaneous applications. Each end-use tends to have specific requirements of the plaster in terms of set time, linear expansion, compressive strength, etc. These requirements impose restrictions on the plaster suppliers in terms of production lot sizes, technical sales support, and product distribution. Some of the more important characteristics of the major types of industrial plasters are detailed in the following paragraphs.

Modeling Plasters

These plasters are used mainly in industry for the preparation of original models. Set blocks of plaster have a grain free structure which permits carving or cutting in any direction. When used in the wet form prior to setting, templates can be

formed. The use consistency is in the 60-70 range. Major users of modeling plasters are the figurine industry, the automotive manufacturers, and the aircraft industry. Plasters for use by the figurine industry are called modeling plasters while plasters used in industrial model making are called industrial moulding plaster. The plasters are essentially identical in composition, particle size and particle size distribution, set time, etc. However, industrial moulding plasters generally command a significant premium over modeling plasters used in the figurine industry.

Metal Mould Plasters

These plasters are mixed with refractory materials for the production of moulds for casting non-ferrous alloys. The plaster is generally poured over a wooden model (male) and separated upon hardening to form the metal mould (female). A high degree of control over linear expansion is required in order to reproduce the details of the model. Typical use consistency is in the 60 range. Major customers are the non-ferrous foundries.

Pottery plaster

This is the principal use of plaster in the ceramic industry. Gypsum is used for the manufacture of the case moulds to form the green (unfired) ceramic body of the article. Both the steam autoclave and solution calcined alpha hemihydrates are used; the solution calcined hemihydrate yielding a stronger, lower use consistency plaster. The use consistency is typically in the 45 range. Desirable properties for plasters used in the production of case moulds include the following:

- very low setting expansion to prevent warpage or binding of the block mould
- low use consistency to provide a hard smooth surface, high strength, and to duplicate surface detail
- a reasonable set time to permit mould trimming
- long term dimensional stability

Major consumers of pottery plasters are the sanitary ware and ceramic dinnerware manufacturers such as American Standard, Kohler, Crane, American Olean, Syracuse China, etc.

Tool and die plasters

Jigger and casting mould plasters require the following properties:

- low use consistency
- moderate, uniform set expansion
- reasonably long and uniform set time
- regularity in physical properties of the plaster over a period of years
- ability to make moulds that wear slowly and evenly, absorb water uniformly, yet are sufficiently strong to withstand ordinary abuse

Plate glass plaster

This plaster is used to bed plate glass and optical glass for grinding. It is generally formulated to provide a very quick set, and is usually mixed with an air entrained cement for added strength and early setting properties. The plaster requires a very even particle size distribution as grit would interfere with the polishing process. This plaster use has declined in volume with the development of float glass technology for the production of relatively thick plate glass. However, it is still used when very heavy plate glass is made.

Oil well plaster

This plaster is used in the oil well drilling industry to set the casing in the well. The plaster is formulated with an oil well cement to give it durability. The plaster acts to plug holes in the well and thus reduce the requirement for drilling mud, as well as provide an insulation function in terms of separating the well casing from the surrounding rock. This latter property is important when drilling in permafrost areas. Major customers for this plaster are the well drilling contractors.

The demand for industrial plasters is a function of industrial activity. In 1987, the United States demand for industrial plasters was 496,000 tons. Demand has grown at a compound annual rate of 3.0% since 1974. Demand is expected to grow at a rate of approximately 2% per annum through the year 2000.

Average 1986 and 1987 producer prices for industrial plasters were \$113.71/ton and \$118.20/ton, respectively. However, prices can vary significantly depending upon end use. Variations of as much as 100% for essentially identical plasters sold into different end use markets have been reported.

Specifications for industrial plasters are established by the manufacturers. The plasters are often heavily modified through the addition of set control agents, expansion control modifiers, etc. and are thus proprietary formulations. Nevertheless, it is believed that all producers utilize relatively high purity raw materials (>95% gypsum) for the manufacture of industrial plasters.

Fillers

Gypsum fillers are used in a variety of applications. The principal end-use is in joint compounds for application with gypsum wallboard. Finely ground gypsum is also used as a filler in plastics and in paint, paper, food, and pharmaceutical applications. The 1987 demand for gypsum fillers in the United States was approximately 300,000 tons, at an average producer value of \$35.87/ton. Prices, however, can exceed \$400/ton for some grades in some applications. Demand for gypsum in filler and extender applications is expected to increase at a rate of approximately 2.2% per annum through 2000.

The major application of gypsum fillers is in the manufacture of joint compounds. These products are produced by the principal gypsum wallboard manufacturers, and the use of gypsum fillers in joint compounds is primarily one of captive

consumption. Gypsum is used in place of ground calcium carbonate and the decision to employ it depends on the relative costs of gypsum and calcium carbonate. Gypsum may also substitute for other components of the mix. For example, it is believed that USG Corp. employs a percentage of its calcium sulphate fibre, Franklin Fibre, in place of wollastonite and attapulgite in its joint filler formulations. The estimated use of gypsum fillers in joint compounds in the United States is approximately 240,000 tons per year.

Gypsum fillers are also used in plastics, paper, paints, sealants and adhesives. The fillers may be either the uncalcined dihydrate or calcined hemihydrate forms, or the calcined anhydrous form.

Plastics

Gypsum fillers are used to extend both rigid and flexible thermoplastics, and both unreinforced and reinforced thermosets. Gypsum for use in plastics processing is produced in several forms. The dihydrate is generally produced by fine grinding and air separating a high purity, white gypsum. The average particle size is approximately 12µm. The dihydrate is used where a cellular structure is desired, such as in rigid urethane foams. The dihydrate is also used as a substitute for aluminum trihydrate (ATH) as a flame retardant in room temperature curable thermoplastic and thermoset systems. One growing application is for use in spray-up epoxy and polyester fiberglass reinforced tub and shower enclosures. In this application the gypsum is ground to approximately 16µm. It substitutes on a 1:1 basis for ATH. Compounders generally market a mix of gypsum and calcium carbonate (approximately 50/50) for this application. The anhydrous form of calcium sulphate has more extensive uses in plastics formulations.

The anhydrous nature of the material permits its use in applications where the resin processing temperatures exceed 100°C. Anhydrous calcium sulphate is marketed in several particle sizes, typical values being 12µm, 7µm, 4µm, 2µm, 1.4µm, and 1µm. A decrease in the average particle size provides for greater dispersibility and even distribution in the resin mix, with a high resin/filler contact for maximum structural strength and integrity. Anhydrous calcium sulphate is pure white in colour, grading 98 or 99 on the Beckman scale. Whiteness is important as the material can substitute to some extent for TiO₂. Gypsum fillers are used in PVC extrusions, polypropylene, nylon, and in polyester systems such as sheet moulding compound (SMC) and bulk moulding compound (BMC). The gypsum improves the impact strength of the plastic and provides for the retention of dimensional stability and dielectric properties. Gypsum fillers are particularly advantageous as replacements for calcium carbonate fillers in halogenated polyester resin systems as gypsum does not react with the halogens. Typical loadings and applications in plastics are as follows:

Thermosets

60-70 phr (parts per hundred of resin); SMC loadings can be over 100 phr

- used in housings, automotive parts, corrosion resistant parts (chemical and marine fittings, etc), electrical applications, recreational equipment parts, power mower housings, power tool handles, appliance bases and covers, furniture components

Thermoplastics

50-60 phr

- used in PVC extrusion applications and cellular vinyl applications to lower cost, improve extrudate smoothness and provide more uniform cell structure
- used in polypropylene extrusions for increased structural integrity and impact strength
- used in high density polyethylene (HDPE) to lower costs used in nylons to lower costs and improve dielectric properties used in PET microwave cookware applications

Gypsum fibres have been developed by USG Corp. as a lower cost substitute for milled glass fibres. The fibre is known as Franklin Fibre and is produced at an 8 million pound/year capacity plant in East Chicago, Illinois. USG has marketed both hemihydrate and anhydrous forms of the fibre for use in both thermoset and thermoplastic applications. The fibre is reported to improve the flexural strength and modulus of elasticity of the resin. Typical prices for hemihydrate fibre are approximately \$0.40/lb, and \$1.50/lb for the anhydrite fibre. USG no longer actively promotes the fibre. The fibre tends to exhibit a high degree of friability and therefore degrades during the compounding and extrusion processes. As a consequence, many of the properties claimed for the fibre were lost. It is believed that USG incorporates a certain amount of Franklin Fibre product in its joint compounds and stucco mixes, where it may act as an anti-slumping agent and partial substitute for wollastonite and attapulgite.

Onoda Cement of Japan has recently announced the start-up of a 20 tonne/year pilot plant for the manufacture of gypsum fibres. This is the only other known gypsum fibre plant.

Paper

Calcium sulphate compounds offer a number of potential advantages in papermaking and paper coating. Principal among these are:

- enhancement to paper properties in neutral and alkaline papermaking such as better fibrous network strength, hence higher fibre replacement; and faster drainage and drying for higher productivity on drainage and dryer limited paper machines
- low cost, especially in comparison to primary pigments such as water washed kaolin, calcium carbonate, titanium dioxide, barium sulphate, etc.
- good brightness, especially for high quality anhydrite
- high bulk, thereby providing a low gloss, non-glare coat-

ing and porous surface which readily absorbs printing inks

- high smoothness due to the high bulk properties of gypsum, hence low shrinkage on drying. This property is most significant for blade coating, the principal coating process used today
- matte finish, hence reduced glare due to the high bulk and porous surface of the gypsum coating
- porous surface, promoting fast drying of printing inks
- distinctive feel, hence imparting a tactile characteristic in filled papers which may be associated with high quality

Despite this extensive list of desirable properties, gypsum and anhydrite have found only limited use in papermaking and paper coating in North America. The principal disadvantages of gypsum and anhydrite in papermaking and paper coating are:

- high solubility in wet-end papermaking
 - leads to large material losses in the white water unless the white water system is closed
 - contributes to excessive plugging of paper machine felts due to both crystallization of the dihydrate and scaling problems in the wet end system
- reduced hydrophobic sizing if used at the 10%-20% furnish level
 - although cationic alkaline sizing may be improved by the calcium ion in conjunction with bridging type anion retention aids
- high coating viscosities
 - bad for the rheology (deformation and flow) of coating applications and for drying. Even low (30% solids) slurries are very thick compared to about 70% solids slurries for clay
- clay flocculation (coalescence into cloud-like non-crystalline mass)
 - occurs in multi-pigment coatings due to the dissolved calcium ion;
- latex coagulation of anionic latex binders used for coatings
 - leads to inadequate bonding of the coating to the basestock fibre, and hence problems in printing due to the weak surface;
- low print gloss and ink holdout in comparison to plastic pigments
 - give both high bulk and high printed gloss;
- abrasiveness
 - leads to high wear of papermaking drainage fabrics, forming boards, and cutter knives abrasiveness is probably due to the presence of coarse, hard grit; or could be due to crystallization of gypsum in the wires and foils
- poor pigment suspension in the wet end of the papermaking system

Despite these problems, gypsum and anhydrite have been used in various papermaking operations. The major applica-

tion to date has been as a substitute for calcium carbonate in the manufacture of gypsum linerboard. In this application the hemihydrate is applied to the surface of the paper during the gypsum setting process. It provides for an increase in the gypsum/paper bond strength. A more recent application has been as a substitute for calcium carbonate filler in alkaline sized papers. Gypsum can also substitute for kaolin as a filler for some grades of paper. These applications require the higher brightness anhydrous forms of gypsum. The use of gypsum as a replacement for TiO_2 in paper manufacture is not well developed. The gypsum generally lacks the required opacity and can only be used to a limited extent in this application. However, it appears that European papermakers are beginning to use increasing quantities of gypsum and anhydrite as a coating material.

USG has marketed two grades of paper fillers in recent years, Britone and Paper Brite. Both grades are derivatives of USG's standard filler product line. The Paper Brite grade is believed to have been a mixture of gypsum and aluminum trihydrate (ATH). The specifications for the two grades are detailed below:

Britone

Brightness 97 GE
particle size 325 mesh, 5-7 μm
anhydrous, "dead burned" grade
alkaline pH
platelet particle shape
Applications: filler, coating, coarse paper grades

Paper Brite

Brightness 98-99 GE
particle size 99.5% passing 325 mesh
anhydrous, "dead burned" Snow White grade mixed with ATH
alkaline pH
Applications: coating, fine paper grades

Paints, Sealants and Adhesives

Gypsum fillers are used in textured paints and as fillers and extenders in sealants and adhesives manufacture. The principal competition is from calcium carbonate fillers. Use of gypsum in these applications is believed to be very limited.

The estimated use of gypsum fillers in plastics, paper, paint, adhesive, and sealant applications in the United States in 1987 is approximately 30,000 tons per year. The fastest growing application is as a substitute for ATH in spray-up polyester/FRP applications. Gypsum for this application costs approximately \$0.04/lb, while ATH costs approximately \$0.175/lb. Gypsum use in plastics, paper, and adhesives is expected to show good growth and to be the most promising market during the next 10 years.

Foods and Pharmaceuticals

Food and pharmaceutical applications represent a demand of approximately 12,000 tons in North America per year. In these applications the gypsum is used as a calcium supplement in bakery products, as a bleaching and stabilizing agent for cheese and yogurt, as a gelatinizing agent and wort clarifier in beer brewing and wine making, and as a diluent and calcium supplement in pharmaceutical applications. Specific applications and limitations on use are detailed in the regulations of the Food and Drug Administration (FDA) of the United States and the Food and Drug Directorate (FDD) of the Dept. of Health and Welfare in Canada. For example, the FDA allows the following calcium sulphate additions to food stuffs:

ice cream, ice cream mix, ice milk	0.5%
sherbet	0.75%
creamed cottage cheese	0.05%
tomatoes, canned vegetables, frozen apples	0.11%
canned apples	0.11%
flour, whole wheat flour	0.09%
bread	0.5%

Pharmaceutical applications are more limited than food applications. The principal use in pharmaceutical preparations is as an active ingredient in multi-vitamin tablets, where the gypsum provides a source of calcium. The use of gypsum as a binder or excipient is limited by the abrasiveness of the gypsum, and the subsequent brittleness of the tablets. The preferred material is dicalcium phosphate, $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, or a microcrystalline cellulose. In addition, the FDD in Canada does not recommend the use of calcium sulphate in tablet preparation as the solubility of the calcium compounds affects the bioavailability of the active drug ingredients. Other health related applications of gypsum include the manufacture of plaster orthopaedic cast material and the manufacture of dental casts. These applications account for approximately 24,000 tons per year of demand. Orthopaedic plaster is a mixture of alpha and beta stuccos designed to provide a very rapid set and high strength. Dental plasters are produced in four grades, each of which has specific set properties, compressive strengths, and applications. The grades of dental plasters are:

• Type I Impression Plaster:

This is a beta stucco plaster. The required properties are:

- set time of 4 ± 1.5 minutes
- fineness: 98% passing 100 mesh,
90% passing 200 mesh
- set expansion (2hr) $<0.15\%$
- compressive strength (1hr) $5.9 \pm 2\text{MPa}$
- consistency $90 \pm 3\text{mm}$

Type I plasters are used to obtain impressions of the hard and soft tissues of the mouth.

• Type II Model Plaster:

This is also a beta stucco plaster. The required properties are:

- set time of approx. 10 minutes
- fineness: 98% passing 100 mesh
90% passing 200 mesh
- set expansion (2hr) <0.30%
- compressive strength (1hr) 8.8 MPa (min)
- consistency 30 ± 2mm

Type II plasters are used to produce a cast (positive) from an impression (negative) obtained using Type I plaster. The cast is generally maintained as a permanent record of orthodontic work.

• Type III Dental Stones:

This plaster is an alpha stucco plaster. It may be formulated with a wide variety of set control additives, set expansion control additives, fillers, colours, etc. The required properties are:

- set time 10 ± 3 minutes
- fineness: 98% passing 100 mesh
90% passing 200 mesh
- set expansion (2hr) <0.20%
- compressive strength (1hr) >20.6 MPa
- consistency 30 ± 2mm

This plaster is used for casts requiring higher strength and greater abrasion resistance than those produced from Type II plasters. The casts are used for the processing of denture base materials.

• Type IV Dental Stones, High Strength:

This plaster is an alpha stucco plaster. The stucco is of very low use consistency (20-22 ml/100g). The required properties are:

- set time 10 ± 3 minutes
- fineness: 98% passing 100 mesh
90% passing 200 mesh
- set expansion (2hr) <0.10%
- compressive strength (1hr) >34.3 MPa
- consistency 30 ± 2mm

Type IV plasters are used to make casts of individual teeth, for crown or inlay work, and for a complete dental arch.

Specifications for gypsum for use in filler applications are generally set by the end user or by the gypsum supplier. The exception is gypsum for use in food and pharmaceutical applications, where the requirements of the Food and Drug Act and the various pharmaceutical pharmacopeia must be met. Some of these specifications are detailed in Table 2.

Table 2

Gypsum Specifications for Food and Pharmaceutical Use

Pharmaceutical Grades	USP NF	BP
Loss on Drying	anhydrous, <1.5% dihydrate, 19.0-23.0%	
Iron	<0.01%	same
Heavy metals	<0.001%	same
Assay range	98.0-101.0%	same
Loss on Ignition		4.5-8.0%
pH of 20% slurry		6.0-7.6

Typical Properties (Dihydrate)

Density	2.32g/cm ³
Moisture content	19.8%
Particle Size Distribution	0.100 µm-2.5 µm
Specific Surface Area	3154 cm ² /g
Flowability (Carr Index)	48.4%

Note: Gypsum for use in plaster cast bandages should be a minimum of 88% CaSO₄ · 1/2H₂O (BP)

Food Grades	FCC	NF
(Dihydrate)		
Assay	>99.9%	>99.0%
Loss of Ignition	19.0-23.0%	same
As	<3 ppm	same
F	<30 ppm	same
Heavy Metals	<10 ppm	same
Se	<30 ppm	same
Fe	—	<100 ppm

FCC = Food Chemical Code, Title X BP = British Pharmacopeia
NF = National Formulary USP = U.S. Pharmacopeia

4.2 Supply and Trade

USG Corporation is the largest producer of high purity gypsum products in North America. Its Southard, Oklahoma open-pit mine produces 100,000-500,000 tons per year of material. The mine and plant employ about 200 persons. Annual production is estimated to be in the order of 400,000-450,000 tons. The raw material is of high purity (greater than 94%) and high brightness. The Southard plant has the capability of producing both alpha and beta stuccos using a variety of calcining methods.

USG employs about 30 people at a facility in Fort Dodge, Iowa. Annual output is estimated at about 200,000 tons. The gypsum is grey in colour and the plant is capable of producing both alpha and beta stuccos.

USG Corp. also has an 8 million pound/year capacity plant located at East Chicago, Illinois for the production of Franklin Fibre.

USG's annual report discloses that sales of industrial process products amounted to approximately 10% of total gypsum product sales in 1987. Industrial and building plasters and gypsum filler sales accounted for approximately one-half of industrial process sales. Based on this information, USG's plaster, gypsum cement, and filler business represented sales of approximately \$60 million in 1987.

Georgia Pacific Corporation employs about 20 people at an open pit/underground facility in Blue Rapids, Kansas. Annual production is estimated to be in the 250,000 ton per year range. Both alpha and beta stuccos can be produced. There are no data available on the extent of Georgia Pacific's plaster and gypsum filler sales.

Domtar Inc. produces building plasters from an open pit operation at Windsor, Nova Scotia. Annual production is estimated at less than 50,000 tons. Production is confined to beta stuccos. There is no known production of industrial plasters.

Western Gypsum Company is a newly formed company. It is reported to be developing a very high purity gypsum deposit located in southwestern Utah. The company is reported to be targeting the food and pharmaceutical markets. No information is available on the size of the operation.

Synthetic high purity gypsum can be produced from the neutralization of citric acid wastes and other acidic by-products. Miles Laboratories formerly operated a 40,000 ton per year high purity gypsum plant at Elkhart, Indiana. The plant was closed in 1985, but remains available for operation. There are reports that other companies are considering the construction of small scale high purity synthetic gypsum plants as a solution to waste disposal problems. However, none are known to be in operation.

Major European producers of natural high purity gypsum include *British Gypsum*, which selectively mines high purity gypsum at its operations in Newark, Nottinghamshire, and *Borgardts-Sachsenstein GmbH*, which has operations in southern Germany.

USG and Georgia Pacific each produce a comprehensive range of plasters and gypsum cements. The bulk of these products are concerned with applications involving the manufacture of various moulds, patterns, and castings associated with a variety of industries. In addition, there are a number of specialty products used for environmental control, concrete water proofing, etc. The range of products and the specifications for the products are listed in Tables 3, 4, and 5.

There is no detailed information available on the range of building plasters produced by Domtar. It is known that Domtar produces a base coat plaster, a finish or veneer plaster, various mixed plasters, joint compounds, and supplies a plaster for use in the Canadian formulation of Gyp-Crete brand gypsum cement.

USG produces 6 grades of fillers: Terra Alba, Snow White, CA-5, CAS-20-2, CAS-20-4, and LPF2 at its Southard, OK

and Ft. Dodge, IA facilities. The Terra Alba product has an average particle size of 12.2 microns. The Snow White and CA-5 fillers have identical chemical specifications, differing only in particle size. The Snow White product has a mean particle size of 7.8 μ m, with a particle size distribution ranging from 0.4 μ m to 48 μ m. The CA-5 product has a mean particle size of 2 microns, with approximately the same particle size distribution as the Snow White grade. The CAS grades are also identical in chemical specifications to the CA-5 grade, differing only in particle size and particle size distribution. CAS-20-2 has a mean particle size of 2 microns, while the CAS-20-4 has a mean particle size of 4 microns. The LPF2 grade is a finely ground hydrated product which has been recently introduced. The Terra Alba, Snow White, and CA-5 grades are used in pharmaceutical and food applications, and in some plastics applications. The CAS-20 grades are used in plastics filler applications. Both hemihydrate and anhydrite forms of each grade are available. The LPF2 grade is used as a flame retardant filler in tub and spa moulding applications. The specifications for the USG fillers are listed in Table 6.

The British Gypsum specifications for food and pharmaceutical grade gypsum fillers are listed in Table 7.

USG also produces a fibrous calcium sulphate product called Franklin Fibre. This material is available in both the hemi-hydrate and anhydrite form and was developed as a replacement for asbestos and a cheap substitute for milled glass fibre. The product is produced in an 8 million pound/year capacity plant near Chicago. To date, the product has not been entirely commercially successful. Details on the manufacture of the fibre are to be found in Canadian Patent 1,127,374. The specifications for the fibre are provided in Table 8.

Georgia Pacific produces high purity gypsum fillers at its Blue Rapids, Kansas facilities. No detailed information was available from the company respecting its products.

Table 3
USG Industrial Plaster (High Use Consistency) Products Summary

Product Name	Use	Hand Mix	Min. Dry	% Setting	Density		End Use/Application/ Description
	Consistency ¹ (Parts H ₂ O)	Vicat Set ² (Minutes)	Compress. Strength (psi)	Expansion (%)	Wet	Dry (lb/ft ³)	
Moulding Plaster	70	27-37	2,000	0.200	99.0	69.0	utility plaster for casts where expansion control, hardness and strength are not of major importance
Industrial Gauging Plaster	62	27-37	2,400	0.220	102.0	75.0	a coarser grind than moulding plaster
White Art Plaster	70	27-37	2,000	0.200	99.0	69.0	same as moulding plaster except it contains a surface hardening agent
No. 1 Casting Plaster	65	27-37	2,400	0.220	100.0	72.5	for figurines, plaques, etc.; same as White Art Plaster except mixed at lower use consistency to incr. strength
Industrial Plaster - PC	75	27-37	2,000	0.190	97.5	65.0	a blend of industrial plaster, polymer and fibre to provide chip resistance and impact strength and allow thinner castings
Pottery Plaster	74	27-37	1,800	0.190	97.6	66.0	for use in most slip casting applications in the ceramic industry
No. 1 Pottery Plaster	70	27-37	2,000	0.210	99.0	69.0	provides a stronger, longer mould; it is the standard of the industry
Puritan Pottery Plaster	66	27-37	2,400	0.220	100.5	72.5	longer wearing mould material recommended for jiggering applications
Regular Dental Plaster	70	19-22	2,000	0.200	99.0	69.0	a normal set dental plaster, similar to moulding plaster
Laboratory Dental Plaster	70	6-9	2,000	-	99.0	69.0	same as regular dental, except for faster set
Impression Dental Plaster	70	3.5-5	2,000	-	99.0	69.0	designed for mouth impression work
Airtrol-E Plaster	-	300-400	-	-	-	-	for spraying on coal refuse piles to control erosion and retard spontaneous combustion or for spraying over sanitary landfills to cover wastes and control rodents
Metal Casting Plaster	140	25-30	-	0.100	84.0	41.0	a combination of industrial plaster, sand, and refractory materials for casting non-ferrous matchplates and patterns

- Notes:
1. Expressed as parts of water by weight per 100 parts of gypsum
 2. Time elapsed from moment plaster and water come in contact until the set plaster is able to support a 300 gram rod and needle in accordance with the Vicat apparatus and procedure (ASTM C472)
 3. Data taken from USG technical bulletins: "US Gypsum Industrial Plasters and Concretes" and "What Gypsum Plaster Can Do For You"

Table 4
USG Industrial Plaster (Low Use Consistency) Products Summary

Product Name	Use	Hand Mix	Min. Dry	% Setting	Density		End Use/Application/ Description
	Consistency ¹ (Parts H ₂ O)	Vicat Set ² (Minutes)	Compress. Strength (psi)	Expansion (%)	Wet	Dry (lb/ft ³)	
Hydrocal B-Base	45	25-35	5,000	0.390	110.6	90.0	for solid and hollow castings of lamp bases and figurines requiring high green strength a white gypsum cement that can be carved or added to (Southard, Okla. only)
Hydrocal White	45	25-35	5,000	0.390	110.06	90.0	
Hydrocal Grey	45	25-35	5,000	0.390	110.6	90.0	
Hydrocal C-Base	40	25-35	6,500	0.250	113.7	96.0	same as Hydrocal White, only grey in colour (Ft. Dodge, Iowa only)
Statuary Hydrocal	40	25-35	6,500	0.250	113.7	96.0	
extremely hard and strong with improved plasticity for solid and hollow art casting							
low expansion							
Hydrocal A-11	42	16-20	5,500	0.120	112.5	93.8	high strength with low expansion for master models, Keller duplicating machines and slurry casting
Hydrocal B-11	44	25-35	4,500	0.110	111.2	91.6	
Ultracel 30	38	25-35	6,000	0.080	115.0	99.0	greater plasticity and more setting action suitable for built-up or template framed models
Ultracel 60	39	75-90	5,000	0.065	114.4	97.5	
used where extreme dimensional accuracy is required							
high strength							
Hydrostone	32	17-20	10,000	0.240	119.4	108.7	for high quality art, novelty and stationery castings
Hydrostone Super-X	22	17-20	13,500	0.300	129.0	127.1	
Cerami-Cal	40	18-23	6,500	0.165	113.7	96.0	smooth wearing mould material used in pressing clay ware expands in a controllable manner to compensate for shrinkage in foundry applications
Medium High Expansion Gypsum Cement	48	25-35	-	1.050	108.7	-	
Hydroperm	100	12-19	-	0.140	40.0	-	permeable metal casting formulation
Hydrocal FGR ⁴	30	50-70	-	-	-	-	high strength cement for use with glass fibre for fabricating glass reinforced products
Firecode CT	125	120-180	150	0.100	65.0	25.0	fire rated cement for curtailing spread of cable fires in cable trays and through walls
Duracal	26	25-35	8,500	0.250	131.0	110.0	for paving highways, bridges, loading docks, etc.
Environstone	-	-	-	-	-	-	binder designed for solidification of industrial wastes, creates a monolithic solid to allow for permanent disposal

- Notes:
1. Expressed as parts of water by weight per 100 parts of gypsum
 2. As per ASTM Specification C472
 3. Data taken from USG Technical Bulletins: "US Gypsum Industrial Plasters and Gypsum Cements", "Duracal Cement" and "New! Environstone Cement"
 4. Includes 5-6% glass fibre by weight

Table 5
Georgia Pacific Plaster and Gypsum Cement Products Summary¹

Product Type	Colour	Use Consistency ²	Setting Time (Minutes)	Setting Expansion (in/in)	Dry Compressive Strength (psi)	Hardness (Monotron)	Uses
K-55 Pottery Plaster	White	76	25-35	0.0006	1,700	16	A,B,C,D
K-58 Plaster	White	72	25-35	0.0015	1,800	17	A,B,C,D
K-59 Pottery Plaster	White	70	25-35	0.0015	2,000	18	A,B,C,D
K-62 Pottery Plaster	Blue	68	25-35	0.0016	2,600	22	A,B,C,D
Densite K-12 Gypsum Cement	Grey	36	25-35	0.0003	8,000	75	B,E
Densite K-13 Gypsum Cement	Green	38	25-35	0.0003	7,000	72	B,E
Densite K-40 Gypsum Cement	Grey	40	25-35	0.0006	6,800	68	F

Uses:

- A - Models
- B - Block Moulds
- C - Casting Moulds
- D - Jigger Moulds
- E - Case Moulds
- F - Ram Dies

Notes:

1. Data from Georgia Pacific Technical Bulletin: "Industrial Gypsum for Pottery Plaster"
2. Expressed as parts water to 100 parts plaster

Table 6
USG Calcium Sulphate Specifications for Food and Pharmaceutical Products

Typical Analysis	Product Name	
	Terra Alba F&P Grade (uncalcined)	Snow White/CA-5 Filler F&P Grade (calcined)
Total calcium	23.1%	29.2%
CaO	32.31%	40.92%
SO ₃	45.22%	57.46%
CaSO ₄	0.39%	97.68%
CaSO ₄ ·2H ₂ O	96.75%	-
CaCO ₃ ·MgCO ₃	2.06%	1.27%
SiO ₂ + insolubles	0.35%	0.31%
P ₂ O ₅	0.35%	0.31%
Brightness Index	84.4	97.1
Waterloss @ 250°C	20.31%	0.33%
Oil Absorption	23.5%	26.5%
Specific Gravity	2.32	2.96
Bulk Density		
- loose	46.0 pcf	42.0 pcf
- compacted	71.0 pcf	47.0 pcf
Bulking Values		
lbs per solid gal.	19.38	24.43
solid gal. per lb.	0.0518	0.0406
pH		
- 5% slurry	8.8	-
- 10% slurry	9.0	10.4
Refractive Index	1.52	1.58
Particle Size		
< 100 mesh (min)	99.99%	99.9%
< 325 mesh (min)	93.0%	97.0%
Avg. Particle Size	14 microns	7/2 microns

Note: 1. Data from USG Technical Bulletin: "Calcium Sulfate for Food & Pharmaceutical Use"

Table 7
**British Gypsum—
Pharmaceutical Grade Gypsum Properties**

	Ground Super Fine White	Ground FG -2000	Ground White (Hemi-hydrate)
Calcium Sulphate (Min)	99.0%	99.0%	95.0%
Colour (X reflectance 0/45)			
Minimum % vs Barium Sulphate			
White standard	89.0	89.0	72.0
Screen Analysis (BS Sieves)			
+100 (+150 microns)	2.5% max	0.2% max	4.0% max
-100+200(-150+75microns)	15 - 30%	2.0% max	30 - 40%
-200 (-75 microns)	70 - 85%	98.0% min	60 - 70%
Oil Absorption (ml/100g)	33.0	33.0	33.0
pH	6.8 - 7.5	6.8 - 7.5	6.5 - 8.0
Solubility in water @ 20°C (g/l)	2.1	2.1	2.1
Hardness (Moh's scale)	2	2	2
Bulk Density (kg/m ³)			
loose	750-900	700-800	800-950
compacted (lb/ft ³)	1,150-1,250	1,000-1,100	1,200-1,300
loose	46.9-56.3	43.8-50.1	50.1-59.5
compacted	72.0-78.2	62.6-68.8	75.1-81.4

Source: Russell, A.; Minerals in Pharmaceuticals, Industrial Minerals,
Aug. 1988, p.35

Table 8
USG Franklin Fibre Specifications

	Anhydrous (CaSO ₄)	Hemihydrate (CaSO ₄ · 1/2H ₂ O)
Length, µm	60 average (nominal)	same
Diameter, µm	2 uniformly (nominal)	same
Aspect Ratio	30 average (nominal)	same
Oil Absorption, cm ³ /100g	32.0	46.0
Index of Refraction	1.585	1.56
Brightness Index (Beckman)	92	92
True Density	2.8	2.45 to 2.55
Loose Bulk Density, lb/ft ³	16-20	16-20
Fibre Tensile Strength, psi	300,000	same
Fibre Elastic Modulus, psi	26,000,000	same
Moh's Hardness	2.0 to 3.0	same
Chemical Analysis		
CaSO ₄	97.0%	50-70%
CaSO ₄ · 1/2H ₂ O		30-50%
CaSO ₄ · 2H ₂ O		negligible
CaCO ₃ , MgCO ₃	1.27%	1.27%
SO ₃ and insolubles	0.13%	0.13%
Fe ₂ O ₃ and Al ₂ O ₃	0.13%	0.13%
pH 10% slurry	10.4	8.2

Source: USG

Table 9
U.S. Gypsum Trade

U.S. GYPSUM IMPORTS ('000 TONS / \$000)														
	1981		1982		1983		1984		1985		1986		1987	
	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$
Crude	7593	39266	6718	35981	8031	56960	8904	73965	9922	64089	9559	64996	9717	59171
Ground or Calcined	2	339	2	304	4	305	11	392	2	242	3	436	2	384
Alabaster														
Manufactures		1169		1120		1922		3300		5173		6817		6080
Plaster Board		8419		13556		26200		86962		80119		99089		82220
Other														
Manufactures		2527		2685		2492		5048		5799		9829		15726
Totals		51720		53646		87880		169667		155422		181168		163581
U.S. GYPSUM EXPORTS ('000 TONS / \$000)														
	1981		1982		1983		1984		1985		1986		1987	
	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$	Tons	\$
Crude														
Crushed, Calcined	157	14590	123	13319	117	13621	131	12711	83	13021	155	15481	127	15629
Other														
Manufactures		20844		16231		18467		17141		13398		13324		16432
Total		35434		29550		32088		29852		26419		28805		32061

Source: U.S. Bureau of Mines

Most of the high purity gypsum products consumed in North America are produced within the region. There is some trade in gypsum products between Canada and the United States, and between North America and other regions. Data on U.S. trade in gypsum products are provided in Table 9. Canadian imports of gypsum products are almost exclusively from the United States, while the U.S. is the primary consumer of Canadian exports of gypsum products. There is also a small trading volume in high purity gypsum from the U.K. to the U.S. British Gypsum is reported to sell about 2,000 tons per year of very high purity product into the U.S. food and pharmaceutical markets.

Data on Canadian demand for gypsum is of poor quality. The data mainly relate to production of crude gypsum and the production of gypsum wallboard. There is little reliable data on the production or use of gypsum for building and industrial plasters, nor gypsum for use as a filler. Table 10 provides information on Canadian gypsum production and gypsum product manufacture.

The Canada-U.S. Free Trade Agreement can be expected to have an impact on gypsum trade. At the present time crude gypsum shipped from Canada to the United States is not subject to duty. However, finished gypsum products such as wallboard, plasters, and processed products such as gypsum fillers are subject to duties. The rates of duty in each country are as follows:

Table 10
Canadian Gypsum Production and Trade

CANADIAN GYPSUM PRODUCTION							
	1981	1982	1983	1984	1985	1986	Jan - Aug 1988
Gypsum, Crude	7025000	5987000	7507000	7775082	7760783	8802805	
Plain Wallboard	199651	152877	200265	236746	240312	295867	206440
Vinyl Coated & Other Wallboard	-	-	-	2773	2885	2979	2085
Sheeting & Lathers	-	1614	-	-	3129	3321	1490
Dry Joint Filler	23194	14683	16463	16618	18467	20765	22823
Ready Mix Joint Filler	50235	46570	62005	68108	86979	117222	150757

Wallboard data in '000 sq. m
Joint Filler Data in tonnes
Gypsum data in tonnes

CANADIAN GYPSUM IMPORTS TONNES '000											
	1981		1982		1983		1984		1985		Jan - June 1987
	Amount	\$	Amount	\$	Amount	\$	Amount	\$	Amount	\$	Amount
Crude Gypsum	143,500		93,843		100,939		131,809		121,802		221,644
Hardwall Plaster	18851	3307	18926	3724	24728	4633	21427	4538	24632	5836	21307
Gypsum Lath	1577	3	0	0	93	0	0	0	65079	113	4591
Gypsum Wallboard	425622	743	317584	580	450614	636	234308	522	1725463	2383	1649064
Gypsum Basic Products	35398	62	37266	63	40849	95	42158	127	91061	257	137349

CANADIAN GYPSUM EXPORTS											
	1981		1982		1983		1984		1985		Jan - June 1987
	Amount	\$	Amount	\$	Amount	\$	Amount	\$	Amount	\$	Amount
Crude Gypsum	5094873		4775755		5187032		6224574		5879664		5921982
Gypsum Lath, Wallboard & Basic Products	11444352	9282	14385001	13920	26479934	29519	72283606	106104	69970137	116429	76690039
Plasters											135255
											72616713
											108830
											58064
											32337
											5309

Crude gypsum and hardwall plaster data in tonnes
Gypsum lath, wallboard and basic product data in square metres
Source: Statistics Canada

	Imports Into			
	Canada		United States	
	Pre Jan 1/89	Post Jan 1/89	Pre Jan 1/89	Post Jan 1/89
	(MFN)		(MFN)	
Crude gypsum	free	free	free	free
Plaster of Paris, calcined gypsum, prepared plaster	\$0.80/ton	free	\$0.42/ton	free
Ground gypsum, not calcined	free	free	free	free
Gypsum tile	9.2%	*	2.4%	*
Gypsum or plaster building boards and lath	9.4%	*	2.4%	*

Source: The Customs Tariff, Revenue Canada, Customs & Excise Tariff Schedules of the United States

* Duties will be removed in ten equal annual stages commencing on Jan 1/89 and the goods affected will be free of duty effective Jan 1/98.

Reductions in the rate of duty on processed gypsum may pose some difficulty for Canadian producers of processed gypsum products such as plasters, as they are believed to have smaller, less efficient plants than U.S. producers. It can be expected that U.S. producers will be able to increase their penetration of the Canadian market due to increased price competitiveness.

4.3 Commercial Requirements and Trends

High purity gypsum products are sold in a wide variety of end use markets. The individual markets are generally small in volume and require significant sales and technical support from the supplier for their development. The requirements for success in the high purity gypsum business can be summarized under the general themes of business characteristics, business skills, and marketing characteristics. The high purity gypsum business is best classified as part of the extender and filler segment of the minerals industry. Some elements of the business resemble the structural minerals segment of the mining industry, but these tend to relate to the origins of the

industry rather than the factors determining the overall business environment. The major business characteristics influencing the high purity gypsum business are the following:

- The industry tends to be much less cyclical than other segments of the minerals industry. The end use markets for high purity gypsum are more closely associated with non-durable goods and tend to be less cyclical than the markets for structural materials such as gypsum wallboard.
- The high purity gypsum business is relatively small. While the major producers are large companies, the high purity gypsum industry is only about a \$110 million business in total annually.
- The industry typically sells small quantities of specialized products to a diverse range of customers. While captive production is important for one or two end uses, most customers purchase limited amounts of product.
- Technical service is an important factor in the market. Research is very important for success. The research is highly oriented to the development of new products to suit end user needs. As a consequence, the business is highly market oriented. A key to success is understanding end user needs and developing the marketing expertise to service those needs.
- The business is not highly capital intensive. Production plants can be built for less than \$20 million. Nevertheless, the business is not one of easy entry. The technical and marketing expertise required for success are not readily available, and can present formidable barriers to entry.

The business characteristics influence the mix of skills required for success. The critical skills are those allowing for the creation of product differentiation and the opportunity for added value. The most important skills are thus process engineering knowledge, end-use know how, product innovation, technical support, and sales and marketing expertise. Marketing skills are especially important due to the variety of grades offered, and the necessity to differentiate the grades between suppliers. Pricing is not as important as for commodity minerals. High purity gypsums are often sold on the basis of value-in-use rather than cost of production. As a consequence, gross margins for some of the specialty gypsums can reach 100%. There is only a limited amount of international trade in the materials, but significant domestic trade. Distributors play a major role in moving product, with direct sales being applicable only for the largest accounts. In addition, customer sophistication with respect to gypsum uses is low. This limits captive production and strengthens the requirement for customer support.

From the foregoing, it would appear that successful development of the Moose River Basin gypsum deposits will require the participation of a major gypsum producer. It is unlikely that companies outside of the gypsum business would have the required technical, marketing, distribution, and financial skills and resources required to develop the deposit and

move a broad range of products to market. However, companies currently participating in other segments of the industrial minerals business could be successful in the high purity gypsum business. Specific knowledge of gypsum is less important than a sound knowledge of industrial minerals processing in general, and an excellent understanding of industrial minerals marketing.

Some of the more important characteristics of the major end use markets are noted in the following paragraphs.

Building and industrial plasters are generally sold through distributors. Typical distributor-level prices for these products are:

- beta hemihydrate moulding plaster: \$85-90/ton, 50 lb bags, FOB producer plant
- beta hemihydrate pottery plaster: \$95-100/ton, 50 lb bags, FOB producer plant
- alpha hemihydrate plasters: \$125-130/ton, 50 lb bags, FOB producer plant
- Keene's Cement: \$0.20/lb in 100 lb bags

Gypsum plasters and cements are generally sold in minimum 500 pound quantities. Truckload quantities (40,000 lbs) are typical, with carload quantities (120,000 lbs) being the exception. The products are sold FOB producer plant with no freight allowances. Distributors report that gypsum plasters and cements can be economically shipped approximately 900 miles in truck load quantities.

Technical support requirements for the sale of gypsum plasters and cements relate principally to industrial moulding plasters for use in ceramics manufacture, non-ferrous casting and in vacuum forming processes. In these applications the plasters are often heavily loaded with non-reactive fillers to improve the toughness, surface properties or thermal properties of the plaster. Technical sales representatives require a good knowledge of the ceramics, foundry and plastics processing industries.

Dental plasters are sold through dental supplies distributors in small quantities. The distributor will often repackage the plasters in smaller packages for use by individual practitioners. Typical dental plaster prices are in the range of \$1,175-\$3,400 per ton at the distributor level. The plasters are normally sold in packages of 100 lbs or 10 lbs.

There are a wide variety of gypsum fillers on the market. Typical prices, quantities and applications are as follows:

- jointing and patching compounds \$160-\$400/ton, FOB producer plant in truckload quantities. Shipped in 50 lb bags.
- polyester/FRP filler \$80.00/ton, FOB producer in truckload lots particle size average of 16-18 microns
- pharmaceutical and food applications USP Technical Grade: \$0.18/lb, 3,000 lb lots USP NF Grade: \$0.19/lb, 3,000 lb lots
- thermoplastic resin fillers \$80.00/ton, FOB producer in truckload lots particle size below 12 microns

- paper filler applications Britone \$89/ton, FOB producer, dry bulk Paper Brite \$323/ton, FOB producer, 80 lb bags

Gypsum fillers are sold into a diverse range of end use markets. Sales are usually through distributors to specialized compounders, or to large end users such as the food processing industry, pharmaceutical plants, etc. Success in the marketplace is dependent upon detailed knowledge of end user processing technology and applications.

The major technological trends affecting the markets for high purity gypsum are as follows:

- **The development of polymer modified gypsums for improved water resistance**
This is also called macro-defect free gypsum. Small additions of polymers are added to gypsum compounds under very high shear. The resulting products have improved strength and water resistance. The applications are mainly in casting and moulding plasters and high strength gypsum cements. Enhanced development of these products could significantly expand the markets for high purity gypsum.
- **Use of gypsum as a replacement for CaCO_3 filler in plastics and paper**
High purity grades of anhydrite are required. Paper represents an extremely large market potential for gypsum. The limiting factors at present are water solubility and cost. The development of essentially insoluble anhydrite is required. There also needs to be a greater price differential between CaCO_3 and gypsum.
- **The use of gypsum to replace kaolin as a filler in paper**
Low cost additives are required to reduce the problems associated with the use of gypsum as a kaolin replacement.
- **The use of gypsum as a substitute for ATH in plastics and as a substitute for TiO_2 in plastics, paper, and paints**
These applications represent significant potential for gypsum. Research directed towards increasing the opacity of gypsum is required before the full potential can be realized.
- **The development of fibrous gypsum products as a substitute for asbestos and glass fibres**
Research is required to develop a fibre which can withstand the rigours of processing and retain its properties.
- **The potential for large scale displacement of natural gypsum by by-product gypsum in many markets**
If by-product gypsum is developed as a major source of raw material for wallboard manufacture, the available supply will considerably exceed gypsum demand. The excess supply of high quality natural gypsum could have a significant impact on the markets and prices for high purity gypsum, and prevent new sources of gypsum from being developed.

4.4 Market Opportunities

The opportunities available to a new producer of high purity gypsum will be dependent upon successful penetration of selected market niches. The two largest companies currently in the business, USG and Georgia Pacific, have essential control of the market. A new entrant will have to develop specialized product formulations and provide additional customer service in order to be successful. In addition, a new entrant may be forced to accept less than optimum prices for its products. Despite these limitations, it is believed that a new supplier of high purity gypsums could expect to achieve sales of approximately 100,000 tons per annum, provided a good distribution network can be established and good technical sales support is provided.

In terms of developing the Moose River Basin gypsum deposits, the market opportunities will be dependent upon import replacement, domestic market development, and development of export markets. The import replacement market represents a total of approximately 20-25,000 tons per annum. It is concentrated in the building and industrial plasters market. The domestic market for high purity gypsum for use as a filler in plastics, paint, paper, food and pharmaceuticals is underdeveloped. There is believed to be a reasonable opportunity to displace calcium carbonate as a filler in plastics and paper applications, and in sealants and adhesives applications. These applications are believed to represent a potential volume of approximately 20,000 tons per annum.

Export markets are very difficult to quantify. However, it is believed that a Canadian producer of high purity gypsum products could expect to capture a market of approximately 50,000 tons per annum.

Successful entry into the market will be dependent upon the ability to produce products of at least an equivalent purity to those produced by USG at its Southard, OK facility. This means that gypsum of at least 97.7% purity must be produced. A new entrant must also be capable of providing an equivalent range of product grades in terms of particle size, compressive strength, etc. Extensive processing facilities are likely to be required in order to produce the required range of products. As well, significant marketing and technical sales support will be required. These factors tend to indicate that successful development of the Moose River Basin gypsum deposits will require the participation of one of the current gypsum producers, or a leading producer of other industrial minerals. Only these companies have the technical, financial, marketing, and distribution resources and skills to make the project a success.

Other factors affecting successful entry into the market include the following:

• Production Season

The Moose River Basin deposits are in a remote location with a severe winter climate. It can be expected that the mining operations would be most economic if conducted on a seasonal basis under contract.

- **Raw Material Quality**

There is no detailed information available describing the quality of the gypsum deposit and the nature of the mine conditions. Extensive exploration drilling and sample evaluation will be required in order to determine the most appropriate mining methods to employ and establish the beneficiation and processing parameters for the products.

- **Production Scale**

The Moose River Basin deposits are in a remote location and unit production costs can be expected to be relatively high. It is probable that production volumes in excess of 100,000 tons per annum will be required to achieve reasonable unit costs. The most readily available associated market opportunities can be expected to be production of gypsum-wood fibre board and/or production of specialty gypsum wallboard such as Type X or water resistant board. These opportunities have not been evaluated and require detailed study to assess their feasibility.

- **Transportation**

The Moose River Basin deposits are only accessible by rail. Water shipment of gypsum from Moosonee is not feasible due to the short shipping season and the necessity to use shallow draft barges and trans-shipping facilities. However, rail shipment is also expensive. It can be expected that innovative materials handling procedures and low cost freight will be required.

- **Processing Plant Location**

The Moose River Basin deposits are located in a remote area with no population base or infrastructure. It is believed that the most appropriate processing option is to ship the crude gypsum to a location such as Cochrane or Sudbury where a suitable processing plant can be established.



5. Conclusions

THE RESULTS OF THIS STUDY INDICATE THAT THE TOTAL market for high purity gypsum in North America is approximately 1 million tons. The market is highly fragmented in terms of end use, and is dominated by two major producers. These conditions indicate that successful entry of a new producer will be difficult. Nevertheless, it is believed that a potential market of approximately 100,000 tons may be available for a new entrant from Ontario.

Successful penetration of the market will be dependent upon the capability of the producer to establish an extensive sales, marketing, and technical support network. It is anticipated that only a current gypsum producer or perhaps another industrial mineral producer would have the necessary financial, technical, and distribution resources to be successful in the marketplace.

Ontario resources of natural gypsum potentially suitable for the high purity market in North America are located in the Moose River Basin area of Northern Ontario. Beds of massive to banded gypsum are exposed over an area approximately 70 km long by 17 km wide some 60 km southwest of Moosonee. Limited diamond drilling has intersected up to 33m of massive, white gypsum to a depth of 40m towards the north end of the area. Drilling has also indicated that overburden thickness is highly irregular. Average gypsum contents of the beds in excess of 96% are indicated from the analysis of 115 samples from three main study areas. The most promising markets for this gypsum appear to be building and industrial plasters and certain filler applications. Further laboratory test-work and evaluation in this regard appears warranted.



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- U.S. Patent 4,282,192; Aug. 4, 1981; H.V. Larson (to Olin Corp.)
- U.S. Patent 4,080,422; March 21, 1978; R.E. McLeary (to United States Gypsum Company)
- U.S. Patent 4,309,391; Jan. 5, 1982; E. O'Neill (to United States Gypsum Company)
- U.S. Patents 4,421,704; Dec. 20, 1983, and 4,350,736; Sept. 21, 1982; W.S. Reily (to United States Gypsum)
- U.S. Patent 4,454,267; June 12, 1984; T.L. Williams (to United States Gypsum Company)
- U.S. Patent 4,533,528; Aug. 6, 1985; M.F. Zaskalicky (to United States Gypsum Company)

8. Appendices

Appendix 1

Method of Calculation for Gypsum, Anhydrite and Carbonate Percentages and Raw Geochemical Data

Steps:

- 1) $\% \text{MgCO}_3 = \% \text{MgO} \times 2.1$
 - 2) $\% \text{CO}_2 \text{ in } \text{MgCO}_3 = \% \text{MgCO}_3 \times 0.524$
 - 3) $\% \text{CO}_2 \text{ in } \text{CaCO}_3 = \% \text{CO}_2 - \% \text{CO}_2 \text{ in } \text{MgCO}_3$
 - 4) $\% \text{CaCO}_3 = \% \text{CO}_2 \text{ in } \text{CaCO}_3 \times 2.27$
 - 5) $\% \text{CaO in } \text{CaCO}_3 = \% \text{CaCO}_3 \times 0.56$
 - 6) $\% \text{CaO in gypsum and anhydrite} = \% \text{CaO} - \% \text{CaO in } \text{CaCO}_3$
 - 7) $\% \text{H}_2\text{O} = \text{Loss on Ignition (LOI)} - \% \text{CO}_2$
 - 8) $\text{moles CaO} = \% \text{CaO in gypsum and anhydrite} / 56$
 - 9) $\text{moles SO}_3 = (\% \text{S} \times 2.5) / 80$
 - 10) $\text{moles } 2\text{H}_2\text{O} = \% \text{H}_2\text{O (from 7)} / 36$
 - 11) If $\text{moles } 2\text{H}_2\text{O} > (\text{or equal}) \text{ moles SO}_3$ then $\% \text{gypsum} = (\text{LOI} - \text{CO}_2) \times 4.785$ and $\text{anhydrite} = 0 \%$
 - 12) $\text{excess H}_2\text{O} = \% \text{H}_2\text{O (from 7)} - (\% \text{gypsum} \times 0.209)$
 - 13) $\text{excess CaO} = \% \text{CaO} - \% \text{CaO in } \text{CaCO}_3 - (\% \text{gypsum} \times 0.326)$
 - 14) If $\text{moles } 2\text{H}_2\text{O} < \text{moles SO}_3$ then $\% \text{gypsum} = \% \text{H}_2\text{O (from 7)} \times 4.785$ and $\% \text{anhydrite} = [(\% \text{S} \times 2.5) - (\% \text{gypsum} \times 0.465)] \times 1.7$
-

Source: J.E. Muir (Mineral Development Section - MNM)

Appendix 2

Summary of Geochemical Data Major, Minor, and Trace Elements (wt % unless otherwise indicated)

Moose River

	Massive			Banded		
	Mean	StdDev	Range	Mean	StdDev	Range
SiO ₂	0.24	±0.17	0.11-0.71	0.21	±0.19	0.07-0.82
Al ₂ O ₃	<0.01	na	na	<0.01	na	na
Fe ₂ O ₃	0.09	±0.01	0.08-0.11	0.10	±0.04	0.07-0.24
MgO	0.50	±0.31	0.02-1.13	0.47	±0.41	0.01-1.19
CaO	33.6	±1.6	31.2-37.0	33.1	±1.6	30.7-36.3
Na ₂ O	<0.01	na	na	<0.01	na	na
K ₂ O	na	na	<0.01-0.05	na	na	<0.01-0.03
TiO ₂	<0.01	na	na	<0.01	na	na
P ₂ O ₅	<0.01	na	na	<0.01	na	na
MnO	<0.01	na	na	<0.01	na	na
LOI	21.5	±0.4	21.1-22.3	21.5	±0.5	21.0-22.6
S	17.4	±0.5	16.2-18.7	17.8	±1.0	16.5-19.5
CO ₂	1.36	±0.66	0.37-2.86	1.34	±0.98	0.10-3.30
C(T)	0.38	±0.18	0.10-0.80	0.38	±0.27	0.03-0.92
free						
moisture	0.91	±0.48	0.41-2.38	1.27	±0.89	0.32-3.47
U(ppm)<10	na	na	<10	na	na	na
Cl(ppm) na	na	na	<10-80	na	na	<10-120
F(ppm) na	na	na	<100-1000	na	na	<100-280
	19 samples			14 samples		

Cheepash River

	Massive			Banded		
	Mean	StdDev	Range	Mean	StdDev	Range
SiO ₂	0.20	±0.21	0.04-1.08	0.12	±0.05	0.06-0.28
Al ₂ O ₃	<0.01	na	na	<0.01	na	na
Fe ₂ O ₃	0.08	±0.02	0.07-0.21	0.08	±0.01	0.07-0.09
MgO	0.46	±0.58	0.01-3.16	0.42	±0.29	0.01-1.30
CaO	33.0	±0.9	31.0-35.0	33.3	±1.5	31.2-38.7
Na ₂ O	<0.01	na	na	<0.01	na	na
K ₂ O	na	na	<0.01-0.09	na	na	<0.01-0.02
TiO ₂	<0.01	na	na	<0.01	na	na
P ₂ O ₅	<0.01	na	na	<0.01	na	na
MnO	<0.01	na	na	<0.01	na	na
LOI	21.5	±0.9	20.7-25.1	21.4	±0.6	18.9-22.8
S	17.8	±0.8	15.0-18.9	18.1	±0.6	17.1-19.0
CO ₂	1.28	±1.33	0.03-7.48	1.22	±0.74	0.13-3.54
C(T)	0.36	±0.37	0.02-2.07	0.34	±0.21	0.04-0.99
free						
moisture	1.61	±2.15	0.50-12.30	0.90	±0.57	0.36-2.36
U(ppm)<10	na	na	<10	na	na	na
Cl(ppm) na	na	na	<10-170	na	na	<10-340
F(ppm) na	na	na	<100-300	na	na	<100-270
	42 samples			36 samples		

Gypsum Mountain

	Massive			Banded
	Mean	StdDev	Range	
SiO ₂	0.25	±0.12	0.18-0.38	0.10
Al ₂ O ₃	<0.01	na	na	<0.01
Fe ₂ O ₃	0.09	±0.01	0.08-0.10	0.08
MgO	0.36	±0.36	0.05-0.73	0.59
CaO	33.2	±1.0	32.2-34.1	34.0
Na ₂ O	<0.01	na	na	<0.01
K ₂ O	0.02	±0.01	0.01-0.03	0.01
TiO ₂	<0.01	na	na	<0.01
P ₂ O ₃	<0.01	na	na	0.01
MnO	<0.01	na	na	<0.01
LOI	21.3	±0.6	20.8-21.9	21.5
S	18.1	±0.7	17.4-18.9	17.6
CO ₂	1.05	±0.84	0.33-1.97	1.64
C(T)	0.29	±0.24	0.09-0.55	0.46
free				
moisture	2.08	±0.89	1.09-2.80	2.56
U(ppm)<10	na	na	na	<10
Cl(ppm)	na	na	<10-60	60
F(ppm)	na	na	<100-200	<100
3 samples				1 sample
(na - not available)				

Appendix 3

Stucco Production Processes

1) Beta Stucco Commercial Production Processes (North America) Batch Kettle Method

The oldest commercial method for the production of beta stucco is called the kettle method. In this batch process, pulverized gypsum is added to a large vessel called a kettle. The kettle is gradually heated for a period of two to three hours. Calcination begins at a temperature of approximately 77°C, and the calcination process is terminated when the gypsum reaches a temperature of 165-176°C. During calcination the gypsum appears to be boiling due to the evolution of water. The calcination is conducted under atmospheric pressure and in the absence of saturated steam.

Indirectly Heated (Continuous) Kettle Method

The batch kettle process was improved in the early part of this century by innovation and modification into a continuous process. A raw material feed pipe was added to the top of the kettle and a discharge port to the top side of the vessel. A rotating impeller with appropriately positioned blades or paddles was also added which directed raw material feedstock from the top of the kettle down the centre of the vessel and then redirected calcined gypsum back up the outside walls and out the discharge port. The kiln is heated externally at about 150°C. In the 1940's-1950's the calcination process was made more energy efficient by the addition of horizontal "flues" through the body of the kettle and the recycling of hot primary combustion gases through these flues.

Submerged Combustion Continuous Kettle

In the 1960's the production rate of the indirectly heated kettle was improved by over 70% by the introduction of hot combustion gases inside the kettle through a vertical tube or lance. This allowed for higher kettle operating temperatures (170°C) but slightly lower kiln bottom temperatures and hence, longer kiln life. Overall natural gas consumption per unit of production was also improved.

Calcidyne Process

Developed in the 1960's, this continuous process essentially involves the injection of pulverized gypsum and hot combustion gases into a long tubular vessel. Control of the vessel temperature, product reaction time, and vessel length affect product quality and process efficiency.

Flash Calcined Raymond Impmill (Impact Mill)

During the 1970's there were several impmill installations at Canadian wallboard plants. In this process minus

9mm gypsum is fed to gas-fired impmills where calcination and final grinding take place simultaneously.

Claudius Peters Roller Ring Mill (CPRRM)

The CPRRM represents a further evolution in combining the calcination/pulverization/particle sizing steps, and hence, a further overall increase in efficiency. An enclosed bottom gas-fired roller ring mill is combined with a cyclone and gas burner. Gypsum is fed into the mill, pulverized, calcined and passed through the cyclone. The finished product is separated by the cyclone and discharged from the vessel, the remainder is recycled through the mill and calcination zone.

Some technical information on the production processes for beta hemihydrate and anhydrite are disclosed in the following patents:

- U.S. Patent 1,984,201, U.S. Gypsum
Process for the continuous kettle calcination of gypsum. This patent relates to a continuous kettle calcination process wherein the gypsum is heated in a stream of hot air or gases.
- U.S. Patent 4,533,528, U.S. Gypsum
Process for continuously calcining gypsum to low dispersed consistency stucco. This patent relates to a continuous kettle process for the production of a stucco suitable for use in wallboard production and some building plasters. The process differs from Patent 1,984,201 in that the gypsum is calcined in the wet state rather than dried prior to calcination.
- U.S. Patent 3,236,509, U.S. Gypsum
Process for the continuous fluidized bed calcination of gypsum.
This patent relates to the use of a continuous fluidized bed calcination process to calcine gypsum. The process differs from Patent 4,533,528 in that the gypsum feed is dried prior to calcination.
- U.S. Patent 4,080,422, U.S. Gypsum
Process for the flash calcination of gypsum feed with concomitant self-comminution of the feed.
This process provides for the continuous flash calcination of the gypsum feed in the presence of hot gases. The process differs from the other patents in that the feed material is ground to a finer particle size and the calcination process takes place in a co-current rather than vortex or fluidized bed manner.

2) Alpha Stucco Commercial Production Processes

As discussed in this report, there are only two major producers of alpha stuccos in North America: USG Corporation and Georgia Pacific Corporation. Both companies are extremely secretive about their alpha gypsum production technology and therefore no details could be obtained from these sources. Nevertheless, it is known

that alpha hemihydrates are generally produced by three means: autoclave, salt solution, and slurry calcination in an autoclave or salt solution.

The autoclave method is the oldest. It relies on the calcination of lump gypsum of approximately 25mm size in an autoclave for approximately 5-7 hours under a saturated steam pressure of 15-20 psig (pounds per square inch gage). The method is described in U.S. Patent 1,901,051. Later variations of this method incorporate the use of a finer grind raw feed, pre-soaking of the gypsum in a crystal habit modifier such as succinic acid, and the use of crystal habit modifiers and incremental pressure increases. The process results in the formation of a soluble alpha hemihydrate.

The salt solution process incorporates heating a dihydrate in a water solution containing a metallic salt such as CaCl_2 . The pressure is maintained below atmospheric. The resulting alpha stucco is claimed to have a low water demand.

In the slurry calcination process the gypsum feed material is first put into a slurry with excess water and a crystal habit modifier and then calcined under pressure. After calcination the water is blown off and the product dried to produce a soluble hemihydrate. Slurry calcined plasters generally require approximately 25% less water for re-hydration to produce a pourable mix. Slurry calcined alpha plasters thus yield a much stronger, denser set than steam calcined alpha plasters. The hemihydrate may be converted to the anhydrite by heating to approximately 260°C for short periods of time.

Ortech International, formerly Ontario Research Foundation, an Ontario-based research organization, has also developed an alpha stucco production process. The process is comprised of an indirectly heated autoclave in which either (a) "a suspended steel cage containing gypsum rock or (b) a gypsum/water slurry is treated at a temperature of 150-180°C at 50 psig pressure for less than one hour". When gypsum rock is treated, boiler generated steam is injected into the vessel.

A continuous slurry autoclave process is now under development. In this process a gypsum slurry comprised of about 25% solids is fed into an enclosed helical column. The column is maintained under pressure and heat is applied to the system. The quality and properties of the desired alpha stucco are controlled by varying the residence time, column pressure, and system temperature.

Insoluble alpha anhydrites are produced by the lump process, by calcination in rotary kilns, or by flash calcination. The lump process is the oldest technique. It requires the calcination of 10cm to 30.5cm gypsum rock pieces in a beehive kiln at high temperature (480-677°C)

for 60-80 hours. The rotary kiln method calcines the gypsum at temperatures above 370°C. The calcination times are relatively short due to the use of relatively fine gypsum feed material. Keene's cement is normally produced by rotary calcination. The flash calcination process is the most recently developed. It is described in the previously mentioned U.S. Patent 4,080,422.

Typical use consistency and compressive strength data for stuccos produced by the various methods are detailed below:

	Use Consistency (ml H_2O /100g stucco)	Compressive Strength (psi)
Production Method		
Beta Hemihydrate		
kettle stucco	60-100	750-2,000
continuous kettle	60-120	750-2,000
submerged combustion		
kettle	60-120	750-2,000
flash calcination	50-90	750-2,000
rotary kiln	70-90	750-2,000
Alpha Hemihydrate		
dry autoclave	40-50	5,000-12,000
slurry calcination (autoclave or salt solution)	32-50	5,000-12,000